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Sedimentation and Stratigraphy of the Mount Rogers Formation, Virginia

Kenneth Morris Blondeau

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SEDIMENTATION AND STRATIGRAPHY
OF THE
MOUNT ROGERS FORMATION, VIRGINIA

A Thesis

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Master of Science

in

The Department of Geology

by

Kenneth Morris Blondeau
B.S., Louisiana State University, 1970
August, 1975

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TABLE OF CONTENTS

	PAGE
ACKNOWLEDGEMENT.	ii
LIST OF TABLES	v
LIST OF FIGURES.	vi
LIST OF PLATES	viii
ABSTRACT	ix
INTRODUCTION	1
GEOLOGIC SETTING	4
STRATIGRAPHY	9
LITHOGENETIC UNITS	17
Conglomeratic Mudstone.	17
Argillite	24
Microrhythmites.	31
Megarhythmites	39
Greywacke	46
Polymict Conglomerate	51
Arkosic Sandstone	57
Quartz Pebble Conglomerate.	60
AGE.	65
CORRELATIONS	66
ORIGIN OF THE MOUNT ROGERS FORMATION	71
Evidence of Late Precambrian Glaciation	71
Criteria for the Recognition of Ancient Glaciations	73
Origin and Characteristic Features of Glacial Deposits.	75
Paleoenvironments of the Mount Rogers Formation	83
Paleogeography of the Upper Sedimentary Member.	88

TABLE OF CONTENTS (CONTINUED)

	PAGE
BIBLIOGRAPHY.	97
APPENDIX.	102
PLATE I	in pocket inside back cover
VITA.	117

LIST OF TABLES

TABLE	PAGE
I. Numbers of Microrhythmites Per Inch in Measured Units	32
II. Numbers of Megarhythmites Per Inch in Measured Units	39
III. Interpretation of Mount Rogers Lithologic Units. . .	84

LIST OF FIGURES

FIGURE	PAGE
1. General location of study area.	3
2. Geologic provinces of the Appalachian Mountains . .	5
3. Generalized regional cross section showing the relationship of the study area to major structural features	6
4. Upper Precambrian Stratified Units of the Appalachian Blue Ridge Province	7
5. Major Thrust Faults and Structural Units.	10
6. Generalized Geologic Section Showing Mount Rogers Formation Members	11
7. Generalized Section of the Upper Sedimentary Member of the Mount Rogers Formation.	13
8. General Precambrian-L. Cambrian Stratigraphy of SW Virginia, NW North Carolina, NE Tennessee. . . .	16
9. Conglomeratic Mudstone.	19
10. Stratified Conglomeratic Mudstone	21
11. Slumped Mudstone Unit	27
12. Outsized Clasts (Dropstones).	29
13. Microrhythmites	34
14. Clast size versus stratification thickness (Microrhythmites)	37
15. Megarhythmites.	41
16. Clast size versus stratification thickness (Megarhythmites).	44

LIST OF FIGURES (CONTINUED)

FIGURE	PAGE
17. Greywacke (Turbidites)	48
18. Polymict Conglomerates.	53
19. Quartz Pebble Conglomerate.	62
20. Distribution of Infra-Cambrian Tillites	72
21. Environmental model for the upper sedimentary member of the Mount Rogers Formation.	89
22. Facies evidence for direction of ice movement .	90
23. Generalized paleogeography and directional information of the study area	91

LIST OF PLATES

PLATE	PAGE
I. Geologic Map of Study Area Mount Rogers Formation.	in pocket inside back cover

ABSTRACT

The Mount Rogers Formation of southwestern Virginia is a thick, upper Precambrian sequence of interbedded conglomeratic mudstones, rhythmically layered argillites, arkosic sandstones and conglomerates, polymict conglomerates, and associated rhyolitic and latitic flows and pyroclastics. The conglomeratic mudstone consists of unsorted, angular to subrounded grains, ranging in size from silt up to boulders one meter in diameter, enclosed within a fine-grained hematitic matrix or cement. The rhythmically layered argillite is made up of thin, alternating couplets of light, very fine-grained sandstone or siltstone grading upward into dark red argillite. Many of the couplets contain "outsized" exotic clasts which penetrate and deform underlying laminae and are overlain by undeformed laminae. Irregularly interbedded within the rhythmically layered argillite is a second population of thicker graded units composed of fine-grained sandstone containing shale rip-up clasts and exhibiting massive, flat laminated and small-scale cross-bedded zones which resemble Bouma intervals. The polymict conglomerate consists of rounded cobbles and pebbles of plutonic, metamorphic, volcanic and sedimentary rock embedded in a matrix of poorly-sorted coarse-grained arkose. The conglomerate is characterized by large-scale festoon cross-bedding, lateral impersistence of individual beds, and poor sorting.

The sedimentary units of the Mount Rogers Formation are interpreted as a sequence of glacial and periglacial deposits including tillite (conglomeratic mudstone), glacio-lacustrine or glacio-marine varves (rhythmically layered argillite), interbedded turbidites, and glacio-fluvial debris (arkosic sandstone and conglomerate and polymict conglomerate). The sediment source included an older plutonic, metamorphic terrain and a penecontemporaneous rhyolitic volcanic complex.

INTRODUCTION

Upper Precambrian glacial deposits have been described from most of the world's continents, including several reported occurrences in North America (Harland and Rudwick, 1964). Among the latter are pebbly mudstones or diamictites described from the Kingston Peak Formation of the Pahrump Series in southeastern California (Hazzard, 1937), the Headquarters Schist of the Libby Creek Group in Wyoming (Houston and others, 1968), the Mineral Fork Formation in northern Utah (Blackwelder, 1932; Condie, 1967; Crittenden, 1952), the Mount Rogers Formation in the central Appalachians (Rankin, 1967; 1970), and the Gowganda and related Huronian formations in Ontario, Canada and adjacent areas of southeastern Canada and peninsular Michigan (Coleman, 1926; Ovenshine, 1964). The principal evidence for the glacial and periglacial origin of these units includes the unsorted, unstratified texture of tillite units which contain angular, faceted and striated boulders; grooved pavements; and the close association of tillitic units with fluvial conglomerates and varved argillites containing rafted stones.

Because of the difficulty in distinguishing between very poorly sorted rocks of glacial origin and the deposits of various subaerial and subaqueous gravity flows (e.g., alluvial debris flows,

subaqueous slumps and mudflows, and volcanic lahars, Frakes and Crowell, 1967), the origin of some of these units remains uncertain. With the recognition of the role of submarine slumping in the deposition of poorly sorted sediments, several units formerly interpreted as of a glacial origin have been restudied and ascribed to mass-movement deposition (Dott, 1961; Newell, 1957; Lindsey, 1969).

The Mount Rogers Formation of the Blue Ridge of southwestern Virginia, northeasternmost Tennessee, and northwesternmost North Carolina (figure 1) includes in its upper part sedimentary units similar in appearance to tillite and varved argillite. Early investigators (Jonas and Stose, 1939; Stose and Stose, 1944; 1957) suggested a volcanic and pyroclastic origin for the entire sequence; Carrington (1960) related the varve-like rhythmites to cyclic pyroclastic volcanism. The more recent studies of Rankin (1967, 1970), however, have alluded to the possible glacial and periglacial deposition of portions of the Mount Rogers sequence.

The purpose of this study is to provide a detailed description of the strata and the stratigraphic facies relationships within the upper sedimentary member of the Mount Rogers Formation and to evaluate the relative importance of glacial and other possible modes of deposition. The interpretation of the depositional history of this sedimentary sequence and evidence of its deposition under cold climate conditions will be presented.

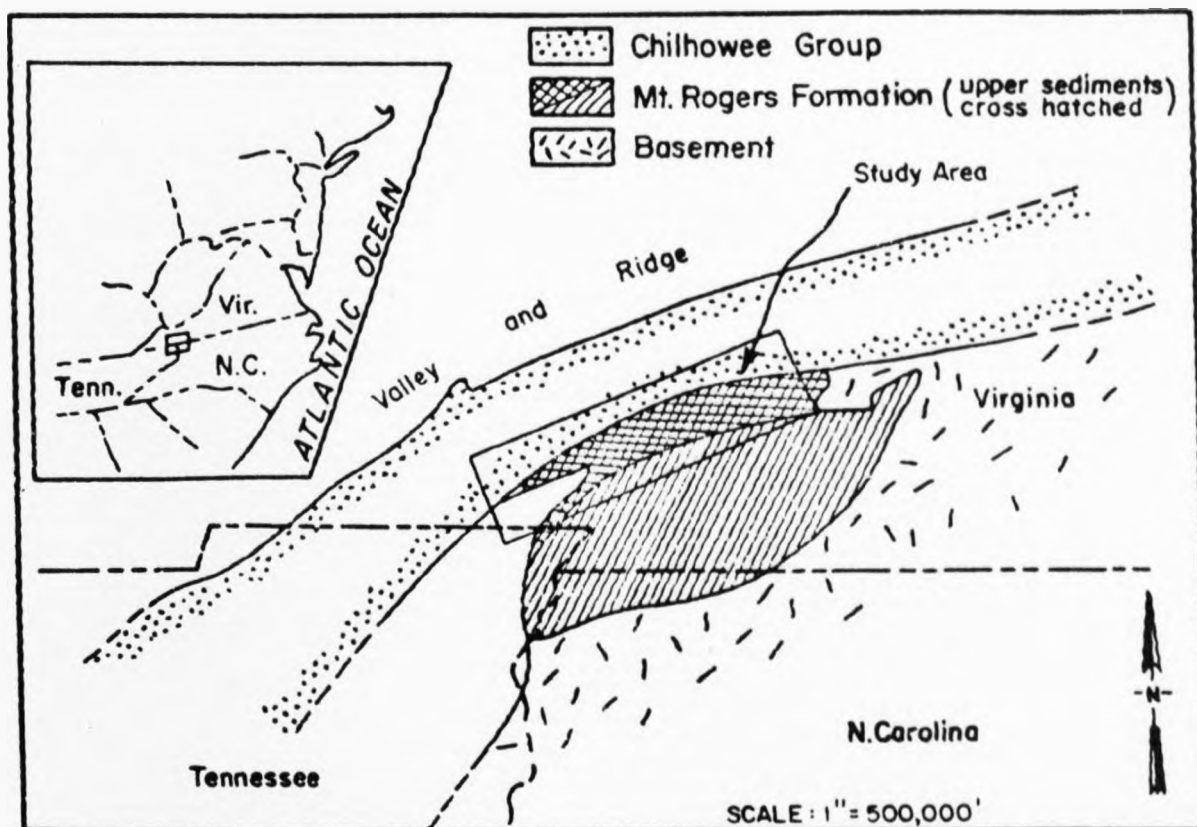


Figure 1: General location of study area

Adapted from: Geologic Map of Virginia
(Va. Division of Mineral
Resources, 1963)

GEOLOGIC SETTING

The Blue Ridge Province, in which the study area is located, extends from southern Pennsylvania to northern Georgia (figure 2). It is bounded to the northwest by the Valley and Ridge Province and to the southeast by the Piedmont (Fisher and others, 1970). The northwest boundary with the Valley and Ridge is a complex series of large, NE-SW trending, low angle thrust faults along which Precambrian and Paleozoic rocks have moved northwestward across the imbricately faulted but unmetamorphosed Paleozoic rocks of the Valley and Ridge (figure 3). Marking the southeastern edge of the Blue Ridge Belt is the Brevard Zone, a narrow belt of low-grade metamorphic rocks which are intensely sheared and appear to represent a fundamental structural boundary (Reed and others, 1970).

The Blue Ridge makes up the northwesternmost part of the crystalline Appalachians and consists largely of gneisses and gneissic granites and variously deformed and metamorphosed sedimentary and volcanic rocks of Precambrian age (Bryant and Reed, 1970). Locally, Paleozoic miogeosynclinal rocks rest directly on this basement complex, but throughout much of the Blue Ridge, thick sequences of only slightly metamorphosed late Precambrian sedimentary rocks lie between the Precambrian basement and the overlying Paleozoic strata (figure 4) (Rankin, 1970; Reed, 1970).

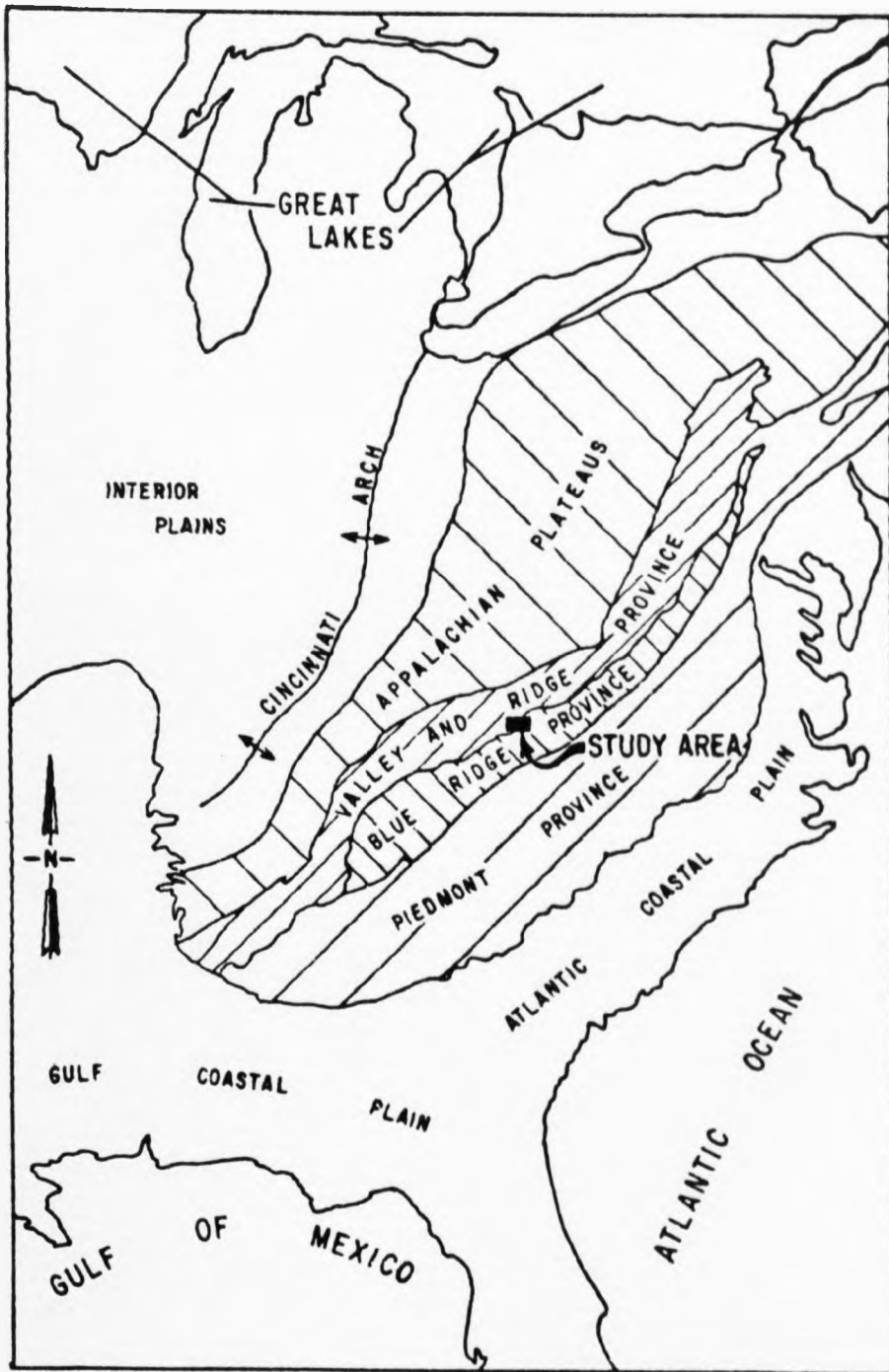


Figure 2: Geologic provinces of the Appalachian Mountains

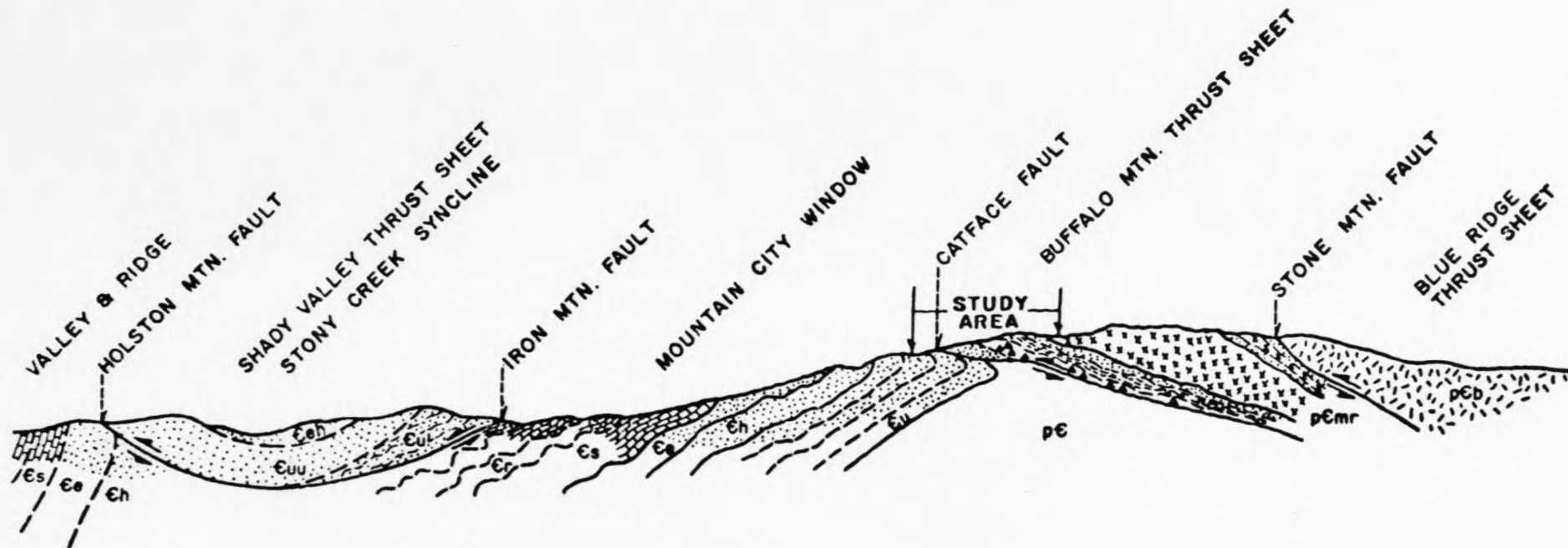
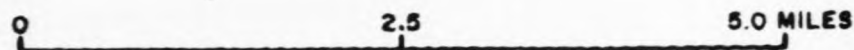


Figure 3: Generalized regional cross section showing the relationship of the study area to major structural features (see figure 5 for location A-A')

From: King and Ferguson, 1960



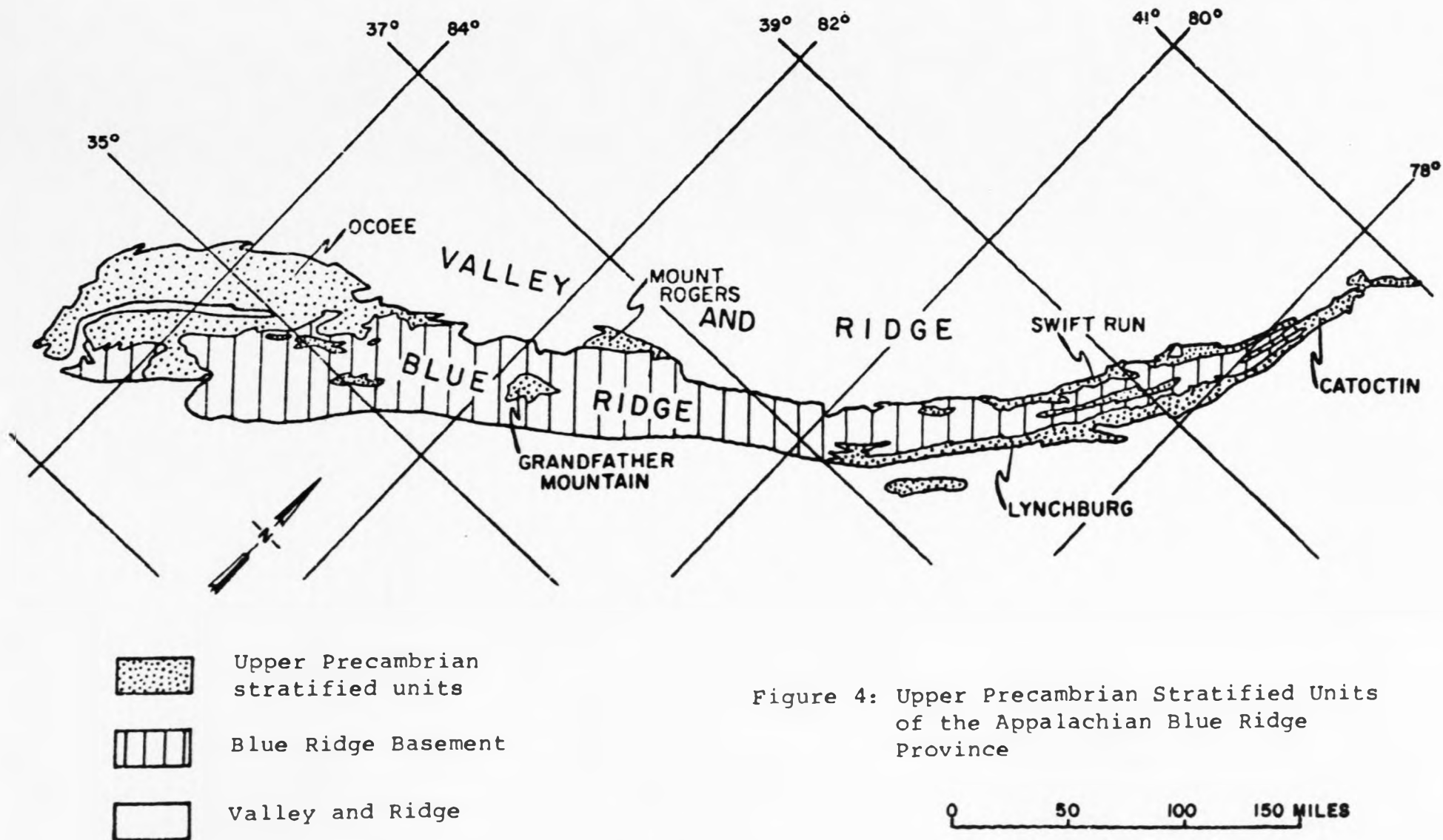


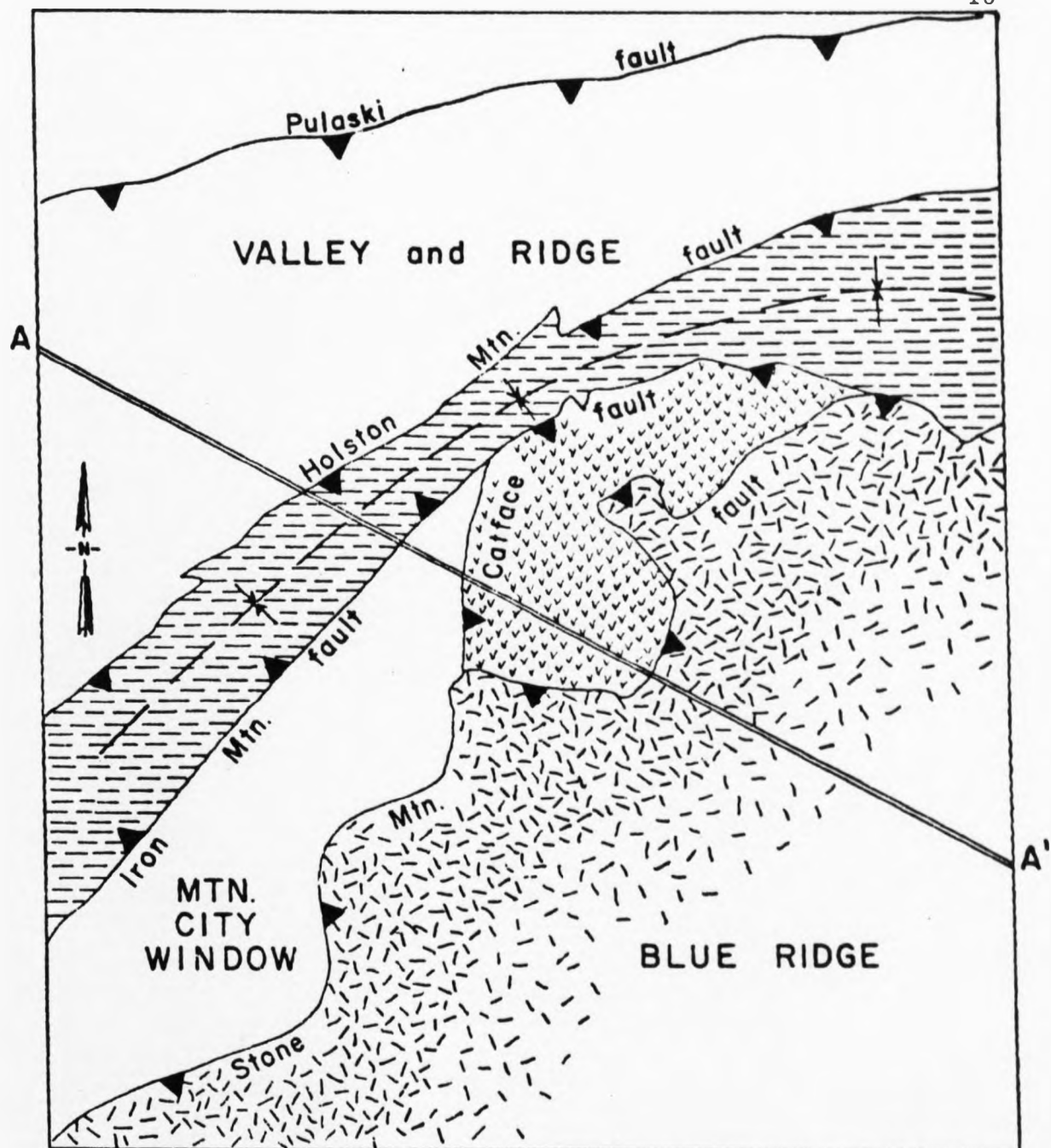
Figure 4: Upper Precambrian Stratified Units of the Appalachian Blue Ridge Province

These upper Precambrian units unconformably overlie the lower Precambrian basement complex and consist mainly of clastic sedimentary, metasedimentary, some felsic and a few mafic volcanic rocks.

STRATIGRAPHY

In extreme southwestern Virginia, northeastern Tennessee, and northwestern North Carolina, the Precambrian basement of the Blue Ridge is overlain by a thick, complex sequence of interstratified and interfingering sedimentary rocks and acidic volcanics named the Mount Rogers Series by Stose and Stose (1944) and subsequently the Mount Rogers Formation by Rankin (1970). This formation lies within an area dominated by imbricate Paleozoic thrust faults and related folds. Four major low angle thrusts - the Holston Mountain fault, Iron Mountain fault, Stone Mountain fault, and the Catface fault - divide the region into five structural units (figure 5, also see figure 3). The Mount Rogers Formation is tectonically situated in a series of three overlapping thrust sheets, the Shady Valley, the Buffalo Mountain, and the Blue Ridge (Rogers, 1970; Rankin, 1970).

Rankin (1970) divided the Mount Rogers Formation into three unnamed members; a middle volcanic member separating a lower sedimentary and volcanic sequence from an upper sedimentary sequence (figure 6). This investigation deals only with the upper sedimentary member, which can be traced as a belt between one and three miles wide for approximately thirty miles along strike (figure 1).



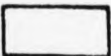
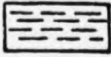
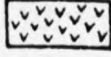
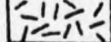
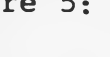
- | | |
|---|---|
|  | Valley and Ridge Belt |
|  | Mountain City Window |
|  | Shady Valley Thrust Sheet
(Stony Creek Syncline) |
|  | Buffalo Mountain Thrust
Sheet |
|  | Blue Ridge Thrust Sheet |

Figure 5: Major Thrust Faults and Structural Units
Modified from: Rankin, 1970

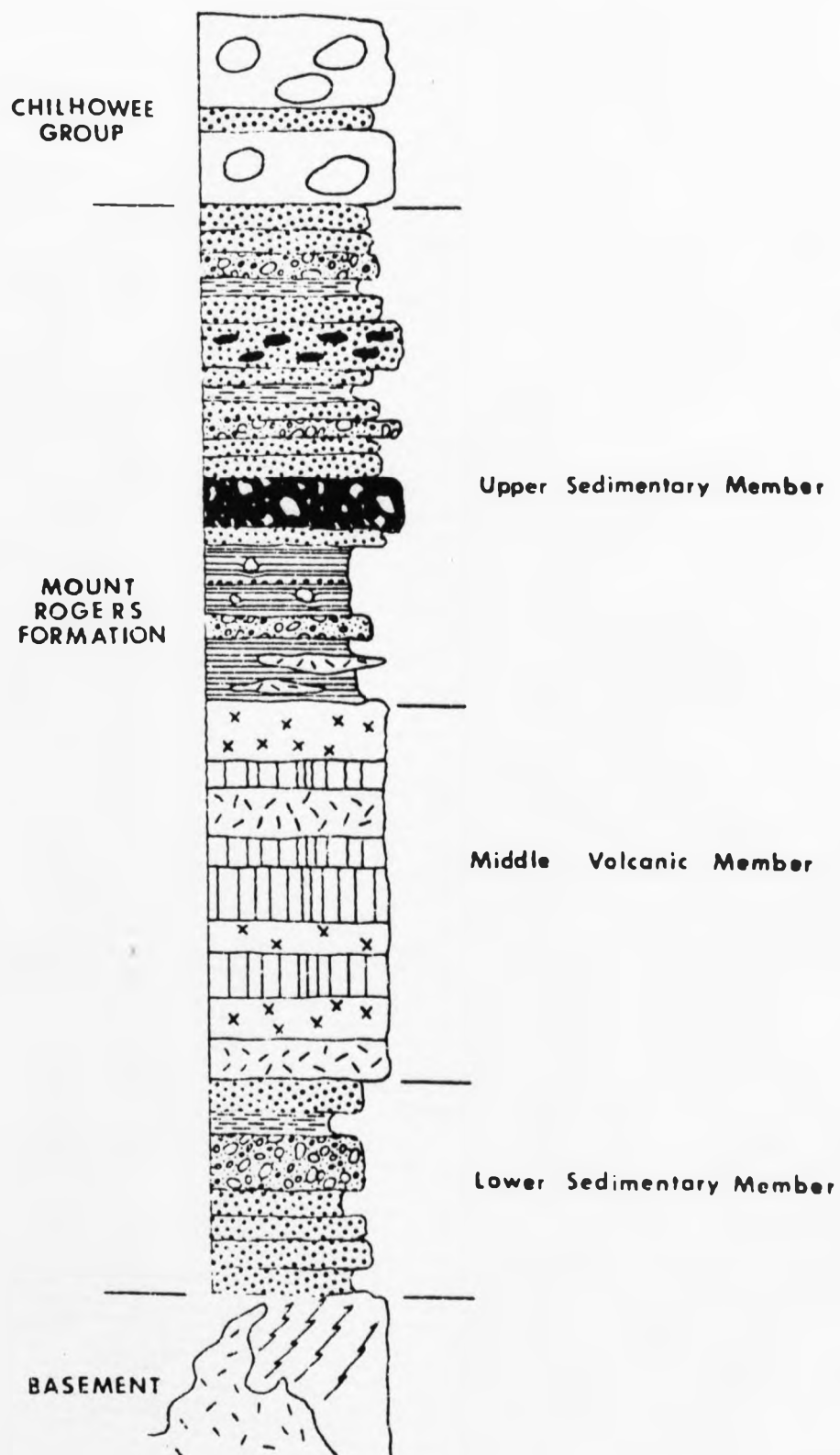


Figure 6: Generalized Geologic Section Showing Mount Rogers Formation Members

The lower sedimentary member was not studied as part of the present investigation but appears to be made up largely of sedimentary rock similar to that of the upper member, including conglomeratic mudstone, rhythmically layered argillite, and arkosic sandstone and conglomerate. Although the lower contact of the Mount Rogers Formation is not present within the study area, it has been described as an unconformity between the sedimentary strata and igneous and metamorphic basement, the Cranberry Gneiss (Jonas and Stose, 1939; Stose and Stose, 1957; King and Ferguson, 1960; Rankin, 1967; 1970).

The overlying volcanic complex of the middle member consists of approximately 5000 feet of interbedded rhyolite flows, pyroclastics, and associated latitic and basaltic units.

The upper sedimentary member, the subject of the present investigation, consists of a complexly interbedded and interfingering association of arkosic sandstone and conglomerate, conglomeratic mudstone, rhythmically layered argillite, and quartz pebble conglomerate (appendix 1). Figure 7 illustrates a generalized stratigraphic section through the upper sedimentary member of the Mount Rogers Formation. The general position within the sequence of the lithogenetic units shown (i.e. a thick zone of arkose near the base, quartz pebble conglomerate near the top) is maintained across the entire area, although individual beds are usually not tracable between outcrops. The best exposed section,

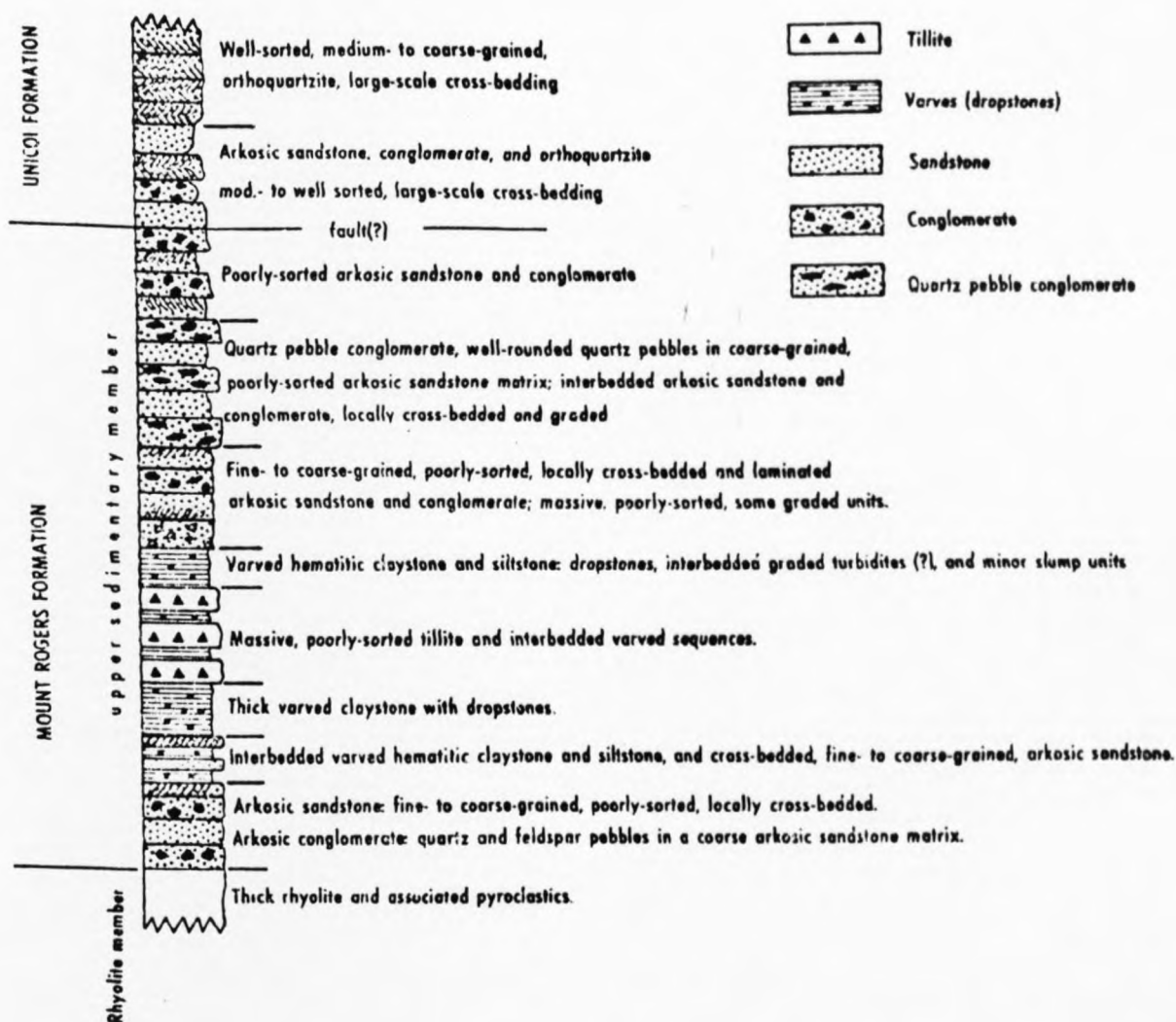


Figure 7. Generalized Section of the Upper Sedimentary Member of the Mount Rogers Formation

here designated as the type section of the upper member of the Mount Rogers Formation, is along the Norfolk and Western Railroad near Creek Junction and near where Star Hill Branch enters Green Cove Creek, Konarock Quadrangle, Virginia (appendix 1).

The upper contact of the Mount Rogers Formation with the overlying Unicoi Formation of the Chilhowee Group appears to be conformable and unfaulted for approximately 25 kilometers across the northern part of the study area. Locally, the uppermost arkosic sandstone and conglomerate of the Mount Rogers passes upward through beds containing less feldspathic debris into quartzites of the Unicoi. The Mount Rogers-Unicoi contact is here placed at the base of a regionally extensive basalt unit below massive quartzites of the Unicoi Formation. Rankin (1970) placed the conformable contact beneath the quartz pebble conglomerate (figure 7) but evidence found in this study indicates that the contact should be much higher in the section. This evidence includes the similarity of mudstone above and below the quartz pebble conglomerate; the lack of orthoquartzites below the basalt; and quartz pebbles embedded in a matrix of arkosic sandstone.

According to King and Ferguson (1960), the Chilhowee Group can be divided into the Unicoi, Hampton, and Erwin Formations; the Hampton and Unicoi being included in the lower Cambrian (?) and the Erwin in the lower Cambrian (?) and lower Cambrian. In general this group is made up of terrigenous clastic rocks including a

basal conglomerate, arkose, clay shale, siltstone, and quartzite, with some basaltic lava beds near the base. The Chilhowee Group passes conformably upward into a sequence of carbonates and shales of the Shady Dolomite and Rome Formation (figure 8) (King and Ferguson, 1960; Rankin, 1970).

AGE	ROCK UNITS		THICKNESS
Lower Cambrian		Rome Fm.	180-1,200'
		Shady Dol.	1,150'
	Chilhowee Group	Erwin	1200-1400'
		Hampton	500-1400'
		Unicoi	2000-5000'
Precambrian	*Younger Precambrian Stratified Sequences	Ocoee Mount Rogers Swift Run Catoctin Lynchburg Grandfather Mtn.	
	Older Precambrian	Cranberry Gneiss and other metamorphic and plutonic units	

*Younger precambrian stratified units are all approximate time equivalent and order in list does not imply stratigraphic sequence.

Figure 8. General Precambrian-L. Cambrian Stratigraphy of SW Virginia, NW North Carolina, NE Tennessee

Modified From: King and Ferguson, 1960

Upper Sedimentary Member
of the Mount Rogers Formation

Lithogenetic Units

Conglomeratic Mudstone

The most distinctive lithologic units in the upper member of the Mount Rogers Formation are the thick beds of well-indurated, matrix-supported, red, hematitic conglomeratic mudstone (figures 9A-B). Individual massive units range from 15 meters to over 275 meters thick, and as many as five and as few as one may be present in any given section. In the vicinity of Creek Junction and Bear Tree Gap (plate 1 - folded map in pocket), these conglomeratic units are thicker and more abundant than to the northeast near Troutdale where only one unit, 37 meters thick, is found. These units are, in most sections (appendix 1), underlain by thick sequences of rhythmite and arkose and are overlain by thick bedded units of arkosic sandstone and conglomerate. Only in the extreme southwestern sections are these units directly overlain by quartz pebble conglomerate. It is important to note that within the upper sedimentary member two distinct types of conglomeratic mudstone are present; the massive or unstratified units as discussed above and units which show poorly developed but distinct stratification (figures 10A-B). These two rock types are complexly interbedded with one

Figure 9. Conglomeratic Mudstone

Locality: Bear Tree Gap Section, Appendix 1

- A. Outcrop of massive, unstratified conglomeratic mudstone.
- B. Boulder of massive conglomeratic mudstone in which poorly-sorted cobbles and boulders are dispersed within a fine-grained matrix. Most light colored clasts are "Cranberry Gneiss". Clasts are angular and are floating in matrix material.

**A****B**

Figure 10. Stratified Conglomeratic Mudstone

Locality: Troutdale Section, Appendix 1
(tillitic mudstone)

A and B. Poorly developed stratification in conglomeratic mudstone. Stratification is defined by darker argillaceous layers, which lack coarser sand and dispersed clasts, interbedded with massive conglomeratic units. Dispersed clasts are poorly sorted, angular to well-rounded, uniformly distributed within conglomeratic layers, and lack any orientation. Thickness of successive conglomeratic units is variable.

**A****B**

another throughout the study area, the stratified units showing better development to the northeast in the area surrounding Troutdale.

In fresh exposures, units of conglomeratic mudstone can be distinguished by their massive appearance and general lack of sorting; most appear as a structureless assemblage of metamorphic and igneous clasts suspended in a matrix of dark brownish-red mudstone (figure 9). The clasts, which form 5 to 30% of the rock, vary greatly in size and rounding, and range from sand up through boulders 1.5 meters in diameter. Most are angular to subangular. The largest cobble noted within the stratified units measured approximately 10 centimeters in diameter. The clasts include a wide variety of plutonic, metamorphic, and volcanic rock types. Pebble counts at outcrops indicate that massive granitic plutonic rocks (including granite, quartz monzonite, and granodiorite) and foliated gneiss make up 60 to 95% of the clasts; rhyolite and other related volcanic rocks, 5-20%; vein quartz, 5-10%; and other types, including basalt, approximately 5%. No systematic variation in clast composition was noted across the study area. The clasts appear to represent erosion of both an older basement terrane (Cranberry Gneiss) and the underlying rhyolitic volcanic complex of the middle member of the Mount Rogers Formation. As a result of induration, the unit fractures across individual clasts rather than around them. Striated faces, therefore, if present, were not seen. Some clasts appear faceted in cross section.

The matrix consists of massive red hematite, most of which is interpreted as representing diagenetic replacement of fine-grained argillaceous sediments by hematite.

No sedimentary structures were observed in the massive conglomeratic mudstone. Although underlying beds have been locally deformed by loading, slumped or contorted beds are not associated with conglomeratic mudstone. As discussed earlier many units exhibit poorly developed stratification.

Thin sections of the Mount Rogers conglomeratic mudstones show angular grains dispersed or floating in a matrix of massive red hematite. Sorting is completely lacking in all Mount Rogers conglomeratic mudstone, and most grains are angular to subangular; in several samples the roundness of grains greater than 1mm in diameter averaged .3 on the Krumbein (1951) scale of roundness. In thin section volcanic, metamorphic, and sedimentary rock fragments greater than 2mm in diameter make up less than 5% of the section. In the size fraction less than 2mm in diameter, the fine hematitic matrix, and the coarser quartz and feldspar particles are in equal proportions. Quartz is approximately twice as abundant as feldspar, and most of the feldspar is seen to be microcline and plagioclase with minor perthite and orthoclase. Sericite alteration of these feldspars is common. X-ray diffraction data shows microcline, plagioclase, and sericite as primary minerals of the conglomeratic mudstones.

On the basis of X-ray diffraction data and thin section studies, hematite has been determined to be the dominant matrix mineral, but quartz and feldspar are also abundant. The hematite is massive and can be seen replacing and embaying both the quartz and feldspar. These grains therefore show corroded surfaces. Based on evidence found, i.e. grains floating in the hematitic matrix and showing corroded surfaces, the hematitic is believed to be secondary or the diagenetic replacement of original matrix material. X-ray data also indicates minor amounts of kaolinite and illite which may represent residual clays.

Argillite

Occurring throughout the upper sedimentary member of the Mount Rogers Formation are distinctive units of maroon argillite. The Mount Rogers argillite includes several types: rhythmically layered argillite (making up approximately 80% of the total argillite within the member), massive mudstone, finely laminated mudstone, mud-chip breccia, and slumped mudstone units which show contorted bedding. The thickest sequence of argillite occurs near the base of the section below the lower arkosic sandstone and conglomerate unit, but argillite can also be found as relatively thin interbeds within the upper sandstones and conglomerates and, in the southwestern sections near Bear Tree Gap, within the conglomeratic

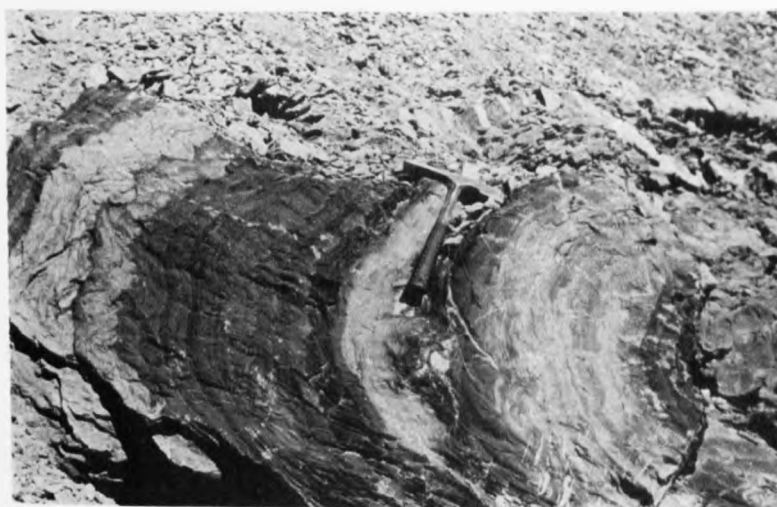
mudstone units (see measured sections, appendix 1). The lowermost sequence consists predominantly of rhythmically layered sediments and slump units (figure 11) interbedded with subordinate, generally thin units of arkosic sandstone, greywacke, laminated pebbly mudstone, polymict conglomerates, as well as massive and finely laminated argillite units. A complete section of this lower sequence is not exposed, but in five measured sections (appendix 1), thicknesses ranged from a maximum of 282 meters to a minimum of 41 meters. The most complete and representative sections are found along the Norfolk and Western Railroad, east of Creek Junction, Konarock Quadrangle, Virginia; and along Virginia Highway 603, west of Trout Dale, Trout Dale Quadrangle, Virginia (plate 1).

Units of rhythmically layered argillite are made up of thin, even, parallel couplets of graded gray siltstone and pink argillite. Individual siltstone laminae typically have a sharp base and grade upward into the overlying argillite. Single couplets range in thickness from less than 1 millimeter up to 4 centimeters, averaging approximately 1 centimeter, and the siltstone laminae tend to be thinner than the associated argillite. Many of these rhythmically layered units contain floating, angular- to sub-rounded plutonic, volcanic, and metamorphic clasts ranging in size from granules to boulders as much as one meter in diameter (figure 12A-B). Clasts greater than 4 centimeters in diameter are rare; those between 1.25

Figure 11. Slumped Mudstone Unit

Locality: Troutdale Section, Appendix 1 (interbedded
varved and slump units)

Contorted bedding of rhythmically layered argillites
(dark bands) and sandstones (light bands).



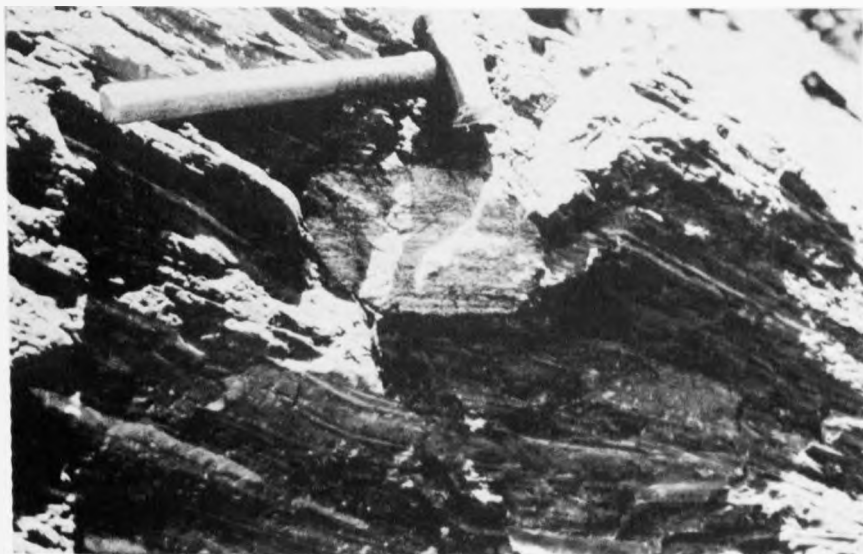
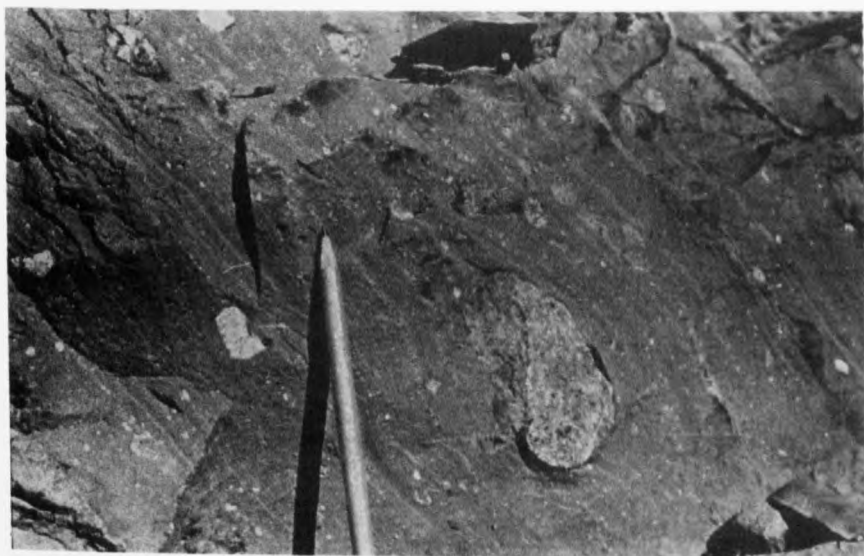
A

Figure 12. Outsized Clasts (Dropstones)

Locality: Creek Junction Section, Appendix 1.

Diameter of clasts exceed the thickness of individual couplets which consist of alternating sandy (light) and argillaceous (dark) layers. Laminae can be seen bending around floating clasts.

- A. Large outsized clast of foliated gneiss. Clast is embedded into and penetrates underlying laminae. Stratigraphic top toward top of photo.
- B. Thinly layered sequence containing poorly-sorted, randomly distributed clasts of volcanic and basement rocks. Distinct layers of granules occur in addition to argillaceous and sandy laminations.

**A****B**

and 2.5 centimeters make up the modal size fraction. Many of the larger clasts are of a diameter greater than the thickness of individual couplets, and can therefore be classified as "outsized clasts" (Harland et al, 1966). The laminae bend around these floating clasts, which are usually embedded into and sometimes penetrate underlying laminae and are overlain by undisturbed layers. The presence of these outsized clasts strongly suggests rafting as an important mechanism of transport during argillite deposition. Outcrop data indicate the composition of the dropstones is similar to that of the clasts in the associated conglomeratic mudstone and polymict conglomerate. Cranberry Gneiss, making up 90-95% of all clasts, predominates. Other types, including rhyolite, vein quartz, and basalt, are present but not common. No pyroclastic ejecta was found.

No cross-beds or ripple marks were observed within the rhythmities, but many of the coarser laminae and interbedded sandstones show sharp basal contacts and a few contain shale rip-up clasts indicating the importance of bottom currents during argillite deposition. Cross-beds, ripple marks, and flat laminations were noted only within the interbedded sandstones. Locally in the northeastern part of the study area the rhythmically layered argillite shows evidence of prelithification slumping (appendix 1). Units of mud-chip breccia and a sandstone-shale mix containing many large clasts or boulders of rhythmically layered argillite

are interlayered with laminated units which have been thrown into contorted slump folds and convolutions.

In order to facilitate further discussion of the rhythmically layered argillite, they can be conveniently sub-divided into two types on the basis of the thickness of individual couplets. The terms "microrhythmites" and "megarhythmites" will be used here to denote relatively thin couplets (less than 1 cm) and relatively thick couplets (greater than 1 cm) respectively. Carrington (1961) first used these terms when he divided the rhythmically layered argillites solely on the basis of thickness into three units, "microrhythmites", "rhythmites", and "megarhythmites". He stated that these terms are arbitrary and all gradations between these can be recognized. The present author's definition of these units varies from that of Carrington and makes use of only two subdivisions, the intermediate "rhythmites" being deleted. Both the microrhythmites and megarhythmites can be found interbedded in some areas (see appendix 1) but in any one outcrop one type will usually predominate; possible genetic differences will be discussed later. Both display the same general characteristics described above, differing only in thickness of individual laminae and in the relative abundance of dropstones.

Microrhythmites

The most common type of rhythmically layered argillite consists of thin, repeated, finely graded mudstone laminae ranging in thickness

from less than 1 millimeter to 1 centimeter. This type of cycle is here designated microrhythmite (figure 13A-C). Microrhythmites dominate western sections (appendix 1, plate 1). Individual units are graded from pink fine-grained siltstone at the base to pink claystone at the top.

The table below lists the number of individual microrhythmites in one inch. These microrhythmites were counted throughout the study area in all measured sections in which microrhythmites were present (see appendix 1). Individual units of microrhythmites ranged up to a maximum thickness of 22 meters. Three counts of the number of microrhythmites in intervals ranging from 2.54 centimeters to 30.5 centimeters thick were made near the base, middle, and top of each bed.

TABLE I

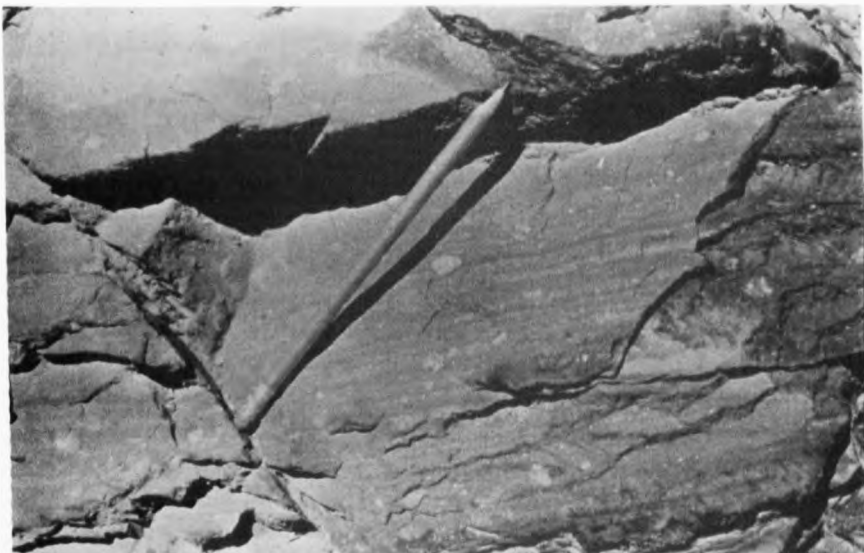
Numbers of Microrhythmites Per Inch in Measured Units

3.0	3.5	4.0	13.5	4.0	9.5
4.0	21.0	14.5	31.0	13.0	5.5
4.0	15.5	10.0	7.0	10.5	12.0
3.0	3.5	10.0	8.0	13.0	7.0
7.0	7.0	4.0	4.5	5.0	10.0
5.0	16.0	5.0	6.0	6.5	
Mean = 8.5/2.54 cm					

Figure 13. Microrhythmites

Locality: Creek Junction Section, Appendix 1.

A-C. Rhythmically alternating sand and granule (light) and argillaceous (dark) zones. Couplets are less than one centimeter in thickness. Laminae contain abundant large outsized clasts of volcanic and basement (gneiss and gneissic granite) rocks. Individual couplets are continuous laterally across outcrops.

**A****B**



c

The average number of microrhythmites in 2.54 centimeters is 8.5; therefore the average thickness of an individual microrhythmite is approximately 3 millimeters.

As a general rule dropstones are abundant within the microrhythmites (figures 12 and 13), forming a distinctly separate, coarser population of grains, but it should be noted that many microrhythmic units contain very few or no isolated clasts. The diagram below (figure 14) modified from Harland et al (1966) shows clast size in relation to stratification thickness. If the diameters of the larger clasts exceed the thickness of the stratification units (beds or laminae), they are considered to be "outsized" clasts and suggest rafting as stated earlier. Also shown on the diagram is the general position of outsized clast in relation to the normal turbidite limit, mudflows, slumps, and slides. The measured diameter of the largest clast from the microrhythmic units of the upper sedimentary member are plotted on the diagram in relation to the average thickness of the individual microrhythmites in which they are found. Many of the plots represent more than one reading at a particular locality.

This diagram clearly indicates the presence of outsized clasts within the microrhythmites. It should be noted that with respect to the strata the larger dropstones or outsized clasts are randomly distributed. No preferred orientation of the dropstones was noted. Fine- to coarse-grained sand, granules, and pebbles occur within the lower parts of most microrhythmites, and in some instances are so

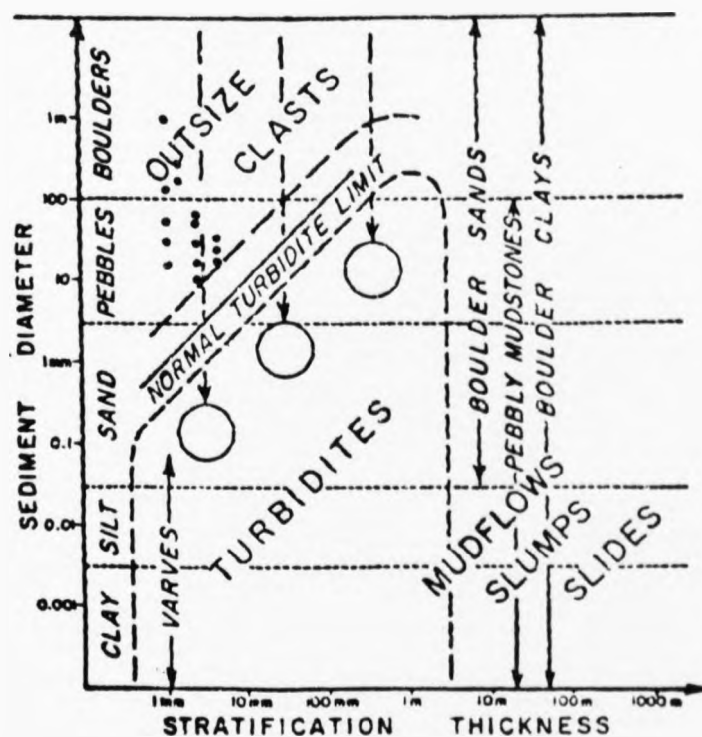


Figure 14. Clast size versus stratification thickness (Microrhythmites). Data from Mount Rogers Formation shown by small solid circles (upper left).

Modified From: Harland et al, 1966

abundant as to form a distinct, coarser lamination below the fine siltstone layer at the base of each unit. Such dropstone layers are typically loaded into the top of the underlying couplet.

Thin sections of the microrhythmites show the coarser laminae as consisting mostly of silt-sized angular particles of quartz and feldspar with a few scattered larger grains of plutonic and metamorphic rock fragments. These laminae can be described as having a grain supported texture, the matrix consisting of clay-sized material. Quartz and feldspar are present in a 3 to 1 ratio; the feldspars being predominantly microcline with minor plagioclase. The feldspars are typically well twinned, and the quartz shows undulatory extinction. Magnetite, epidote, tourmaline, and muscovite were noted as minor constituents. Most of the feldspars show partial or complete sericite replacement. Several distinct laminae of sericite were noted within the coarser layers. These coarser laminae are moderately-sorted and the larger particles range from angular to well-rounded, averaging 0.3 on the Krumbein scale of roundness. The coarser laminae show relatively sharp basal contacts and grade into the upper red laminae which are composed mostly of hematitic, clay-sized material with few floating grains of quartz and feldspar.

X-ray diffraction analysis of the microrhythmites indicates the dominance of quartz, microcline, plagioclase, muscovite, and hematite. Illite and kaolinite peaks are present and could represent residual clay minerals. Also detected were magnetite, epidote, and tourmaline.

Megarhythmites

Megarhythmites (figure 15A-C) are thicker than the microrhythmites, ranging in thickness from 1 centimeter to greater than 4 centimeters. Individual megarhythmites are graded from gray medium- to coarse-grained siltstone at the base to red hematitic claystone at the top. Megarhythmites are most common and probably dominant in eastern sections; the most accessible section is located in a small roadside quarry on county road 603 approximately 10 miles west of Troutdale, Virginia (see Discovery Varve Section; appendix 1 and plate 1).

Table II below lists the number of megarhythmites in 2.54 centimeters. Similar to Table I, these megarhythmites were counted in all measured sections in which megarhythmites were present (see appendix 1). Units composed of megarhythmites ranged up to a maximum thickness of 41 meters; this figure includes

TABLE II

Numbers of Megarhythmites Per Inch in Measured Units

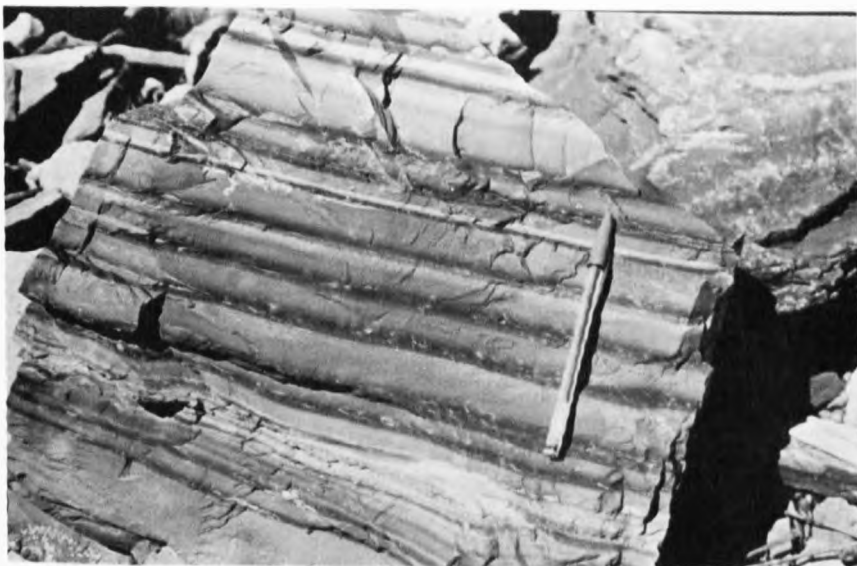
1.5	2.0	2.5	.25	.17	2.0
2.5	2.0	.33	.10	2.2	2.5
1.7	1.7	1.8	2.0	2.0	.75
2.0	2.0	1.5	.77	.30	2.0
.50	2.0	2.0	1.0	1.5	1.5
Mean = 1.5/2.54 cm					

Figure 15. Megarhythmites

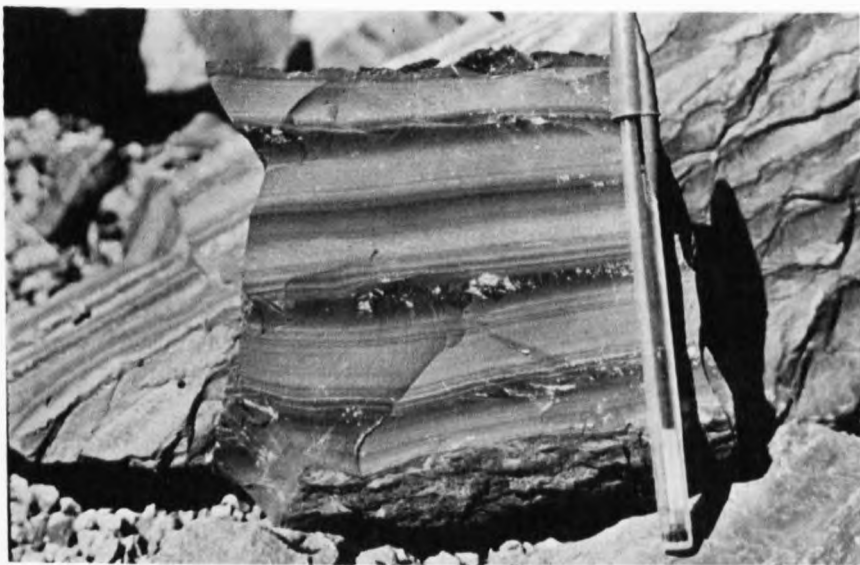
Locality: Discovery Varve Section, Appendix 1.

Rhythmically alternating fine sand and silt (light) and argillaceous (dark) layers. Individual couplets are greater than one centimeter in thickness and grade from gray siltstone at base to darker claystone at top. Rarity of outsized clasts should be noted.

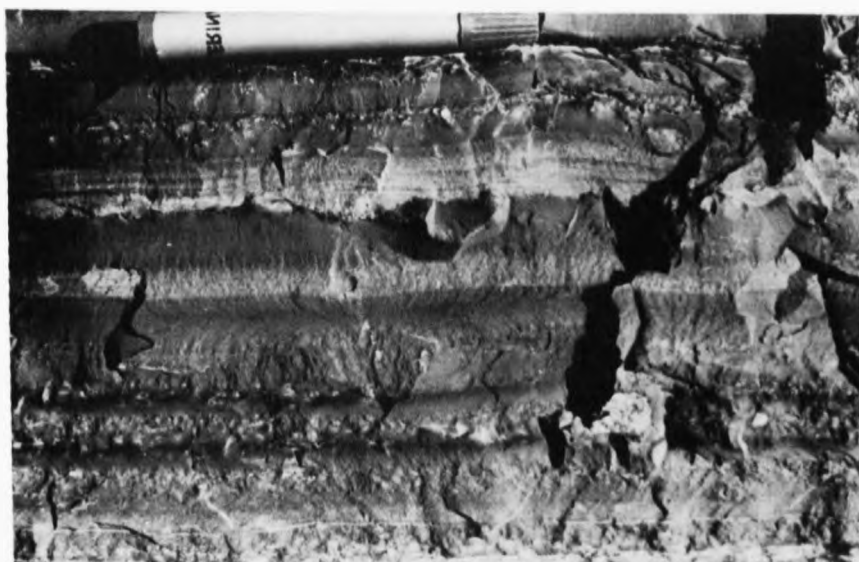
- A. (Light) silt layers have sharp bases and are gradational into overlying (dark) claystone layers.
- B. Rhythmically layered light and dark units showing sublamination indicative of minor fluctuations superimposed on larger sedimentation cycles.
- C. Laminated sandstone near top of photo is graded and shows an irregular basal contact indicative of loading. Similar sandstone units up to 0.5 m thick are common within the megarhythmite sequence.



A



B



C

minor interbeds of greywacke, arkosic sandstones, and slump units. Several of the counts represent average outcrop estimates. For example, if the average thickness of megarhythmites in one outcrop was estimated to be 1.25 centimeters, this was recorded in the table as a count of 2 megarhythmites in 2.54 centimeters. The average number of megarhythmites in 2.54 centimeters is 1.5; therefore the average thickness of an individual megarhythmite is approximately 1.7 centimeters.

Dropstones are uncommon in the megarhythmites as compared to the microrhythmites and, as a population, are of a larger size than those of the microrhythmites. Dropstone layers, which are common in the microrhythmites, are non-existent in the megarhythmites. Larger sand grains are not abundant and most dropped particles occur as isolated, sub-rounded clasts. The measured diameter of the largest clasts from the megarhythmic units are plotted in figure 16 in relation to the average thickness of the individual megarhythmites in which they are found. This figure indicates the presence of outsized clasts within the megarhythmic units, suggesting rafting as the mechanism of transport (Harland et al, 1966). These dropstones are randomly distributed and show no preferred orientation.

Thin sections of the megarhythmites show coarser siltstone laminae grading upward into the thicker hematite claystone laminae.

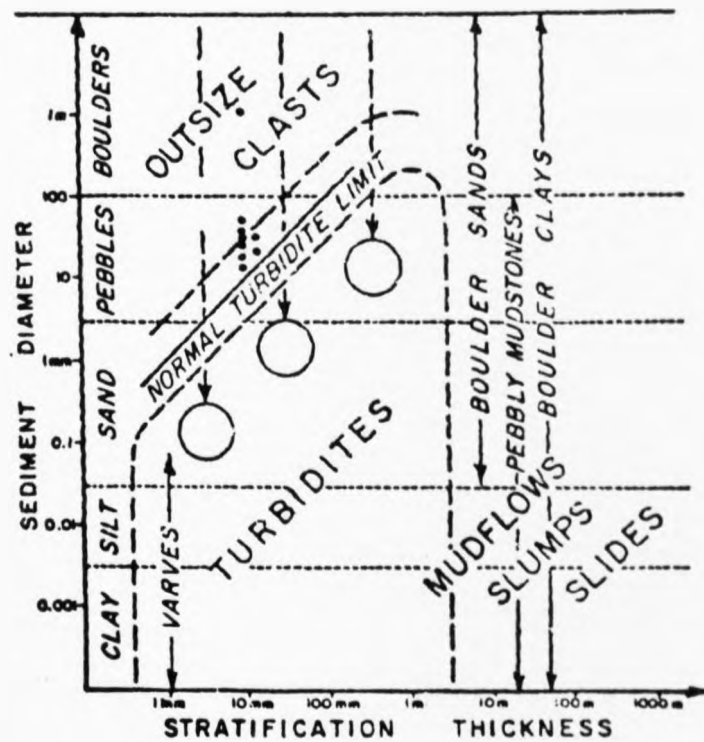


Figure 16. Clast size versus stratification thickness (Megarhythmites). Data from Mount Rogers Formation shown by small solid circles.

Modified From: Harland et al, 1966

In many of the megarhythmites the siltstone layer is separated from the upper claystone by a transition zone containing many smaller dark laminae. Although large dropstones are rare, many sand and silt-sized grains occur floating in the siltstone and claystone. These grains consists of fragments of igneous and metamorphic rocks, quartz, feldspar, muscovite, and minor amounts of magnetite. The siltstone and claystone laminae are lithologically similar to that of the microrhythmites previously described. X-ray diffraction data indicates quartz, plagioclase, microcline, illite, muscovite, and hematite are the primary components with minor chlorite, magnetite, and tourmaline. When the coarser- and finer-ground laminae were x-rayed separately, they were found to be mineralogically identical except for their clay content. The coarser megarhythmite bottoms showed only scattered, ill-defined peaks of montmorillonite and chlorite. The finer red claystone showed illite to be the dominant clay mineral with minor chlorite and montmorillonite.

Greywacke

Interbedded within the megarhythmites (see Discovery Varve Section and Troutdale Section; appendix 1) are thick graded units of fine-grained sandstone. Individual sandstone beds have sharp basal contacts and commonly include rip-up clasts of the underlying red argillite which indicate the importance of bottom currents in the deposition of these units. Many exhibit the sequence of current structures which are known to characterize turbidites; these include a more or less massive interval at the base succeeded by flat-laminated and small-scale cross-bedded zones (figure 17A-D). These graded units range in thickness from 1 centimeter to 22.8 centimeters. Their general appearance and irregular occurrence within the megarhythmites suggest deposition from turbidity currents.

These sandstones can be classified as greywackes according to Pettijohn (1957); they are composed of 55 to 35% quartz and 35 to 60% argillaceous matrix. The matrix consists primarily of recrystallized clay minerals and minor amounts of chlorite. Microcline, plagioclase, muscovite, and magnetite are common as minor constituents. Quartz, feldspar, and other detrital minerals show extensive alteration. Most of the detrital grains are sub-angular, averaging 0.3 on the Krumbein scale of roundness, and are moderately-sorted. Individual turbidite units show well developed grading. In one unit the maximum grain size near the base of the unit is .25 millimeters, the average grain size being .1 millimeter,

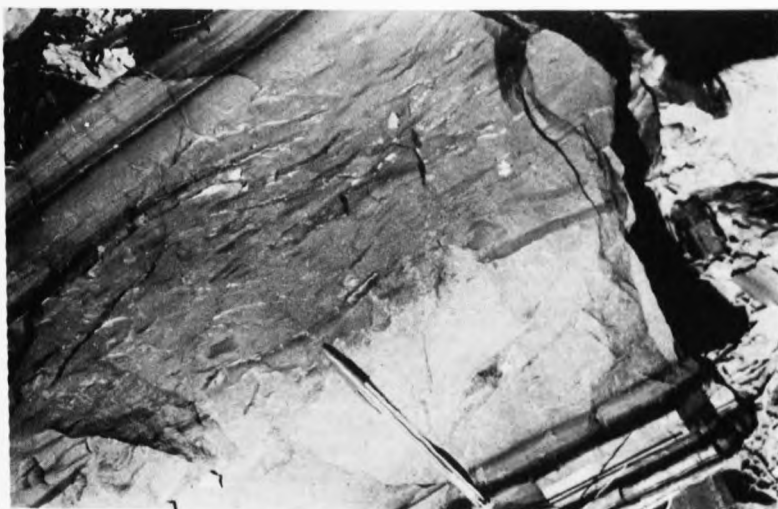
Figure 17. Greywacke (Turbidites)

Locality: Discovery Varve Section, Appendix 1.

Thick graded units of fine-grained sandstone interbedded within the megarhythmites. These units exhibit sharp basal (erosional) contacts.

- A. Hammerhead is on sandstone unit; these units are laterally continuous. Megarhythmites are seen above and below this unit.
- B. Sandstone bed showing sharp basal contact and sequence of internal current structures indicative of deposition from turbidity current: massive interval at the base succeeded by flat-laminated and small-scale cross-bedded zones. Top of unit is rippled.
- C. Close-up of unit in photo 17B. Unit is graded and exhibits "Bouma" intervals.
- D. Massive, graded medium-grained sandstone unit. Included within this unit near the top are rip-up clasts (long dimension oriented parallel to bedding) of an underlying (dark) argillite unit indicating the importance of strong bottom currents in the deposition of these sand units.

**A****B****C**



D

as compared to a maximum of .07 millimeters and an average of .05 millimeters near the top of the unit. The basal contact with the underlying unit is sharp.

Polymict Conglomerate

In the eastern part of the study area, directly below the rhythmically layered argillites and above the middle member rhyolites and tuffs, is a sequence of polymict conglomerates (figure 18A-C) interbedded with rhyolite, laminated mudstones, and bedded pebbly mudstone (see Glacio-Fluvial Section; appendix 1). Within this sequence are two distinctive units of polymictic conglomerates which vary in thickness but measure, at their maximum, about 100 meters and 165 meters respectively and extend along strike for about 2 miles. The best conglomerate exposures are of the upper unit in roadcuts and the adjacent creek bottom along Virginia Highway 603 approximately two miles west of Trout Dale (plate 1). This upper unit pinches out both to the east and the west and is in facies with laminated mudstones. The lower unit strikes west into the Catface thrust and outside of the study area to the east.

The polymictic conglomerate consists of rounded cobbles and pebbles up to 15.2 centimeters in diameter embedded in a matrix of poorly-sorted, coarse-grained, arkosic sandstone. Most of the conglomerate is relatively fine-grained pebble conglomerate with clasts reaching a maximum diameter of 2.5 centimeters and averaging between 1.25 centimeters and 6 millimeters. Coarser polymict conglomerates containing cobbles up to 15.2 centimeters in diameter with an average diameter of around 8.75 centimeters occur in the upper conglomeratic unit. When taken as a whole, the polymict conglomerate is only moderately- to poorly-sorted, although the

Figure 18. Polymict Conglomerates

Locality: Glacio-fluvial Section, Appendix 1.

These photos show fairly well-sorted, rounded cobbles and pebbles embedded in a matrix of poorly-sorted, coarse-grained, arkosic sandstone. Clasts range in size from pebbles up to cobbles fifteen centimeters in diameter.

- A. Festoon cross-bedded, pebble conglomerate. Pebbles are matrix supported. The boulder pictured measures approximately three feet from top to bottom.
- B. Festoon cross-bedded sandstone overlain by matrix supported cobble conglomerate.
- C. Clast supported cobble conglomerate. The darker clasts include rhyolite, basalt and shale; lighter clasts are mostly "Cranberry Gneiss".

**A****B**



c

clasts themselves, apart from the matrix, form a distinct coarser population of coarser, well-sorted grains. The fabric ranges from clast to matrix supported. Most clasts are well- to sub-rounded, but sub-angular ones occur locally. They include a wide range of igneous, metamorphic, and sedimentary rock debris. Outcrop counts of 150 clasts greater than 5 centimeters in diameter show that 40-45% are granitic gneiss, 25-30% rhyolite, 10-15% vein quartz, 5-10% maroon shale, 5-10% basalt, and granite and schist are present as minor constituents. The assemblage appears to represent erosion of the older basement terrane (Cranberry Gneiss), the underlying volcanic complex (middle member, Mount Rogers Formation), as well as penecontemporaneous rhyolites and maroon shales.

The polymictic conglomerates are characterized by well-developed bedding, including large-scale festoon cross-bedding (figure 18A-B) and cut and fill. Individual beds lens rapidly and cannot be traced for any distance. They appear to represent deposition within high energy, alluvial channels.

In thin section, the polymict conglomerate is distinctly bimodal and can be split into two grain-size populations at a diameter of about 1 millimeter. Debris greater than 1 millimeter in diameter makes up about 55% of the thin sections and includes 27% igneous rock fragments, 11% metamorphic rock fragments, 2% sedimentary rock fragments, 7% feldspars, and 8% quartz. These larger grains are poorly-sorted and average 0.6 on the Krumbein

scale of roundness. As seen in thin section, the matrix of the conglomerate is arkosic (Pettijohn, 1957) containing 35% quartz, 28% feldspar, 14% clay-sized material, 5% magnetite, 6% muscovite, 10% calcite, and 2% volcanic rock fragments. Most of the feldspars are plagioclase, microcline, and perthite. The feldspar grains vary from angular to sub-rounded and show partial or complete sericite replacement. The quartz is well- to sub-rounded and shows undulatory extinction; surfaces are corroded and few inclusions were noted. Magnetite is present as well-rounded detrital grains. Calcite, showing typical calcite rhombohedral twinning, is present as an orthochemical constituent. This calcite is found as pore-fillings or cement and as a replacement mineral. Sericite can be seen as a prominent replacement component of the matrix and muscovite is a minor component. Hematite is present only as a very minor replacement mineral and as a local cement.

Arkosic Sandstone

The bulk of the upper third of the upper sedimentary member of the Mount Rogers Formation consists of distinctive units of thickly bedded arkosic sandstone. Although arkose occurs throughout the upper member, there are three mappable units which can be traced for long distances across the study area. These units occur below the conglomeratic mudstone, between the conglomeratic mudstone and the quartz pebble conglomerate, and at the top of the formation above the quartz pebble conglomerate (see appendix 1). These units are highly variable in thickness but show a general thinning to the southwest. A complete section through the lowermost unit is not exposed but in measured sections it averaged approximately 50 meters in thickness. The middle unit, which pinches out to the southwest, measured in three sections from southwest to northeast 90 meters, 140 meters, and 265 meters. The uppermost unit, which is covered in most sections, thins to the southwest measuring an estimated 270 meters in the southwest and 650 meters to the northeast. The best exposure of the lowermost unit is along US 58 approximately two miles west of Konarock, Virginia. The middle and upper units are best exposed along county road 601 one mile north of the intersection with Virginia Highway 603 (see appendix 1; Weaver and Discovery Tillite sections and plate 1).

Individual beds are typically massive, ranging from 10 centimeters to a few meters in thickness. The sandstone is typically maroon to pinkish in color and consists of poorly-sorted, sub-rounded to angular grains of feldspar, quartz, and lithic fragments. Most is medium- to coarse-grained but fine-grained units occur locally. Many contain granules and pebbles of granitic rock, but no clast supported arkosic conglomerate was found. Locally interbedded within the sandstone and conglomerate is maroon shale. Local current structures include flat-laminations, ripple marks, small- to large-scale cross-laminations, and associated graded bedding.

Toward the top of the section, the arkosic sandstone becomes less arkosic, more quartzitic, better sorted, and overall shows a complete transition into the quartzose strata of the overlying Chilhowee Group.

As seen in thin section, the arkosic sandstone exhibits a grain-supported framework of angular to sub-angular grains in a matrix of fine-grained arkosic sandstone. Most is poorly-sorted showing a complete size variation from matrix material less than 1 millimeter in diameter up to 5.5 millimeters, the maximum grain diameter measured in thin section. The average roundness is .1 to .3 on the Krumbein scale, the larger grains being more rounded than the finer ones. Point count data indicates that the sandstone consists of 47% quartz, 13.5% feldspar, 25% clay-sized material, 9.5% volcanic and sedimentary rock fragments, and 4% detrital magnetite.

The fine-grained sandstones are less arkosic, containing approximately 70% quartz and the remaining 30% consisting of, in variable proportions, feldspar, rock fragments, clay-sized material, and other minor constituents including hematite, magnetite, and muscovite. As seen in thin section these sandstones are moderately- to well-sorted and exhibit a grain supported framework of sub-rounded grains embedded in a matrix of clay-sized material.

X-ray diffraction data indicates the dominance of quartz and the feldspars and shows microcline to be the dominant feldspar. This data also indicates that the matrix consists predominantly of sericite with minor amounts of montmorillonite and other clay minerals.

Quartz Pebble Conglomerate

Interbedded with thick arkosic sandstones and conglomeratic units within the upper part of the upper sedimentary member of the Mount Rogers Formation is a zone of thickly bedded quartz pebble conglomerate (figure 19A-B). This zone is persistent and can be traced across the entire mapped area (plate 1). The quartz pebble conglomerate ranges in thickness from over 350 meters in the eastern sections to an average of 50-100 meters in the western sections. Individual beds of quartz pebble conglomerate range up to 3-5 meters thick. Within this zone, quartz pebble conglomerate makes up from 50% of the unit in the eastern sections, to as little as two distinct beds not more than 3-5 meters thick in the western Bear Tree Gap section. The remainder consists of arkosic sandstone. The best exposures of quartz pebble conglomerate are along the Norfolk and Western Railroad cut, just north of where Star Hill Branch enters Green Cove Creek, and along US 58 north of Big Hill, Virginia (appendix 1 and plate 1).

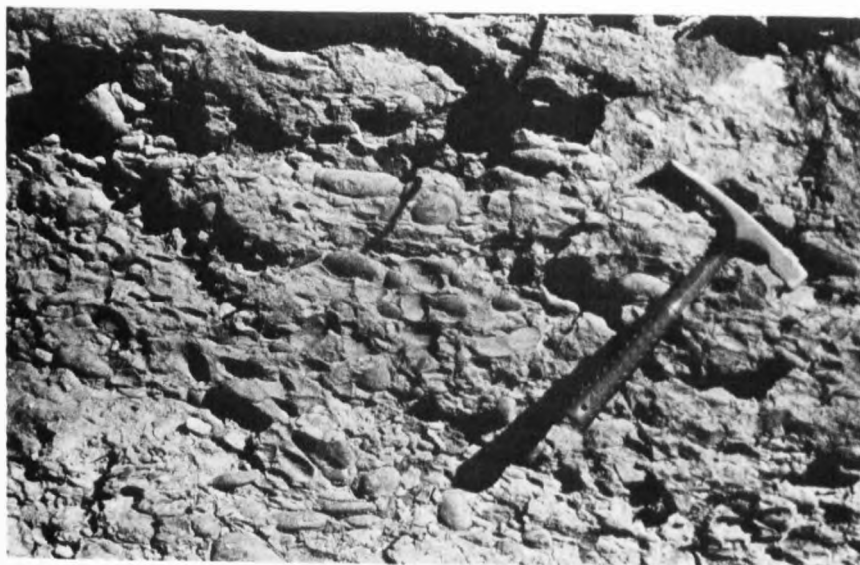
Individual beds of quartz pebble conglomerate are massive, and are characterized by well-sorted, well-rounded vein quartz pebbles enclosed in a poorly-sorted matrix of coarse-grained arkosic sandstone. Outcrop counts of clasts greater than 6 millimeters in diameter show that 75-90% of the clasts are vein quartz and 10-25% of the clasts include rock fragments, feldspars, and chert. No systematic variation in pebble size or composition was noted across the area mapped. Within any given section, well

Figure 19. Quartz Pebble Conglomerate

Locality: Green Cove Creek Section, Appendix 1.

These photos show well-sorted, well-rounded quartz pebbles in a matrix of poorly-sorted, coarse-grained sandstone.

- A. Imbricate (?) quartz pebbles suggesting current direction from right to left.
- B. Massive quartz pebble conglomerate.

**A****B**

rounded quartz clasts range in size from pebbles a few millimeters in diameter to cobbles which reach a maximum of 12 centimeters in diameter. Vein quartz averages 1.25-2.54 centimeters and angular feldspars reach a maximum of 2.54-4 centimeters in diameter and average less than 1.25 centimeters.

In several localities oriented pebbles and cobbles define a crude imbrication. The unit as a whole is well bedded and within the interbedded sandstones are uncommon local occurrences of current structures including both small- and large-scale cross-laminations, minor graded bedding, and flat laminations. No other sedimentary structures were noted.

Thin sections of the quartz pebble conglomerate show the predominance of rounded quartz grains and minor amounts of feldspar embedded in a relatively fine-grained matrix. These sections display a grain-supported framework and are texturally inverted, the well-rounded grains being poorly-sorted. Point count data indicates that approximately 35% of these rock units consist of matrix material which is present as a finer population of grains less than 1 millimeter in diameter and averaging less than .5 millimeters. This matrix material includes 61% quartz grains, 30% clay-sized material, and 9% minor constituents including feldspars, volcanics, and magnetite. The clasts greater than 1 millimeter in diameter make up 65% of the thin sections and

include approximately 52% quartz, 7% feldspars, and 6% sedimentary and volcanic rock fragments. The coarser clasts are better rounded, averaging 0.7 on the Krumbein scale as compared to the finer clasts and matrix material which average between 0.3 and 0.5. These clasts are poorly-sorted, showing a complete size range from 1 millimeter up to the maximum diameter measured in thin section, 14 millimeters.

X-ray diffraction analysis of the quartz pebble conglomerate indicates quartz, chlorite, and microcline are the primary components of these rock units with minor amounts of montmorillonite, muscovite, and magnetite. X-ray diffraction shows chlorite to be the dominant clay mineral of the matrix material.

Age

The age of the Mount Rogers Formation has been well established as late Precambrian (Stose and Stose, 1957; Jonas and Stose, 1939; King and Ferguson, 1960; and Rankin, 1969 and 1970). It unconformably overlies the granitic and metamorphic basement, the Cranberry Gneiss, which has been dated radiometrically at 1050 m.y. (Davis, Tilton, and Wetherill, 1962). Rankin and others (1969) have dated the youngest and median of three massive rhyolites near the middle of the Mount Rogers Formation at 820 m.y. The Chilhowee Group, which unconformably overlies the Mount Rogers, is considered as lower Cambrian and upper Precambrian (?). From beds below the Shady Dolomite, Olenellus Hydlithus, and a few other fossils which indicate an early Cambrian age have been described. Scolithus, a worm tube, is abundant in the Erwin Formation and extends well down into the Hampton Formation (King and Ferguson, 1960). The amygdaloidal basalt of the Unicoi Formation was dated between 440-465 m.y. by helium methods, which places an absolute minimum limit on its age.

Charles Bartlett (oral communication, 1971) reported finding of a linguloid brachiopod in a "Mount Rogers" float boulder, questionably from the Mount Rogers Formation. Because of the uncertainty of the origin of the boulder, the significance of this find is uncertain.

If 550 m.y. is accepted as the base of the Cambrian and if we recognize the upper conformable contact of the Mount Rogers Formation with well established Cambrian and Cambrian (?) sediments and the maximum limit of 1050 m.y., then the Mount Rogers Formation is of definite late Precambrian to lower Cambrian (?) age.

Correlations

Throughout most of the Blue Ridge Province, thick sequences of upper Precambrian stratified rocks like the Mount Rogers Formation occur between the older Precambrian crystallines and the upper Precambrian (?) and lower Paleozoic rocks such as the Chilhowee Group (Rankin, 1967; Reed, 1970). These upper Precambrian rocks unconformably overlies the older basement complex and consist mainly of clastic sedimentary, metasedimentary, and some mafic and felsic volcanic rocks. The stratified rocks include, on the eastern limb of the Blue Ridge anticlinorium: the Lynchburg Formation, Virginia; the Catoclin Formation, Virginia; the Ashe Formation, Virginia and North Carolina; and the Grandfather Mountain Formation, North Carolina; and on the western limb: the Catoclin Formation, Virginia; the Swift Run Formation, Virginia; the Mount Rogers Formation, southwestern Virginia, northeasternmost Tennessee, and northwesternmost North Carolina; and the Ocoee Series, Tennessee, North Carolina, and northern Georgia (figure 4).

Lynchburg Formation

Lynchburg metasediments crop out along the southeastern limb of the Blue Ridge Anticlinorium for about 240 miles and lie between basement plutonic rocks and overlying Catoclin metavolcanics. They consist of layers of metamorphosed clastic rocks ranging from low grade slates and phyllites to high grade biotite and garnet-bearing schist. The original rocks included graywackes, mudstones and conglomerates (King 1970 and Espenshade, 1970). Most of the Lynchburg is characterized by features suggestive of flysch: rhythmic alteration of greywacke units with pelitic beds, graded bedding, slump structures, and by the lack of current-induced features (Brown, 1970). Deposition probably took place in relatively deep water (King, 1970).

Swift Run Formation

Basal Precambrian sediments of the Swift Run Formation lie on the northwest flank of the anticlinorium in the northern part of the Blue Ridge Province and consist of clastic (arkose, graywacke, conglomerate, slate, and phyllite) and pyroclastic rocks and basalt (King, 1970). Because of its stratigraphic position between the Catoclin greenstone and the plutonic basement, it is considered to be the northwestern extent or edge of the Lynchburg Formation, and was deposited on a shelf being cut by the westward advancing sea (Brown, 1970).

Catoctin Formation

The volcanics of the Catoctin Formation, which succeed the basal sediments of the Lynchburg and Swift Run Formations, crop out on both limbs of the northern anticlinorium for approximately 200 miles. The Catoctin metabasalt or greenstone has been interpreted as being subaerial plateau basalt in the Blue Ridge by Reed (1955) and as subaqueous flows further to the southeast by Brown (1970).

Ashe Formation

The thick fine-grained metasediment and metavolcanic Ashe Formation nonconformably overlies the Cranberry Gneiss. It consists mainly of fine- to medium-grained biotite-muscovite gneiss and amphibolite and is interpreted by Rankin (1970) as having been deposited as the seaward equivalent of the Mount Rogers Formation in fairly deep water in a basin which deepened to the southeast.

Grandfather Mountain Formation

Upper Precambrian rocks of the Grandfather Mountain Formation are of a low metamorphic grade and contain metasediments, metarhyolite, and metabasalt. The predominant lithologies are arkose, siltstone, graywacke, and some coarse conglomerates interbedded with metabasalt and other volcanic rocks. The Grandfather Mountain Formation is considered by Rankin (1970) to be transitional between the deep water Ashe Formation to the southeast

and the subaerial and shallow water deposits of the Mount Rogers Formation to the northwest. Hadley (1970) considers it as being the transitional unit between the Mount Rogers Formation and the deep water Snowbird Group of the Ocoee Series. King (1955) states that the Grandfather Mountain Formation closely resembles the Mount Rogers Formation and the two are probably correlative.

Ocoee Series

The Ocoee Series of eastern Tennessee and northwestern North Carolina is a thick sequence of metasedimentary rocks which have been regionally metamorphosed and range from low greenschist facies in the northwest to upper amphibolite facies in the southeast. All these deposits represent an eastward thickening of clastic sedimentary rocks of the Appalachian Geosyncline and are interpreted as marking the hinge of major downwarping of the continental margin in late Precambrian time (Hadley, 1970).

These correlations of the upper Precambrian stratified units in the Blue Ridge Province indicate a basin which deepened to the east and south, there being, in general, deep water lithologies to the east and south and shallow marine to subaerial lithologies to the west and north. There is an eastward thickening of these Precambrian clastics; the older basement rocks to the north and west being the dominant source of detritus. Hadley (1970) states that there were probably several separate but contemporaneous basins which were separated by tectonically active ridges which were marginal to the Precambrian continent.

More recently the Mount Rogers Formation (Crittenden et al., 1971) has been mentioned as being possibly correlative with formations in western North America which are similar lithologically, chronologically, and genetically. These include the Pocatello Formation, Idaho; the Dutch Peak Tillite, Utah; the Mineral Fork Tillite, Utah; and the Kingston Peak Formation of the Pahrump Group, California.

ORIGIN OF THE MOUNT ROGERS FORMATION

Evidence of Late Precambrian Glaciation

Harland and Rudick (1964), Girdler (1964), Cahen (1963), and Harland (1964) have summarized evidence for widespread late Precambrian glaciation. Harland (1964) states that while a critical re-examination of all alleged tillites is desirable to determine the possibility of non-glacial origins, many tillites have already survived such investigations and together contribute to a pattern of extensive ancient glaciation some 600 to 1000 million years ago. The distribution of Infra-Cambrian tillites is almost worldwide. Whether considered according to the present positions of the continents or to a possible Precambrian arrangement, it is difficult to confine them, as are Permo-Carboniferous tillites, to a restricted portion of the globe (Harland and Rudick, 1964). Figure 20 shows the approximate positions of reported Infra-Cambrian tillites according to both the present and possible former positions of the continents. Two hypotheses are proposed by Harland and Rudwick to explain this worldwide distribution; either ice was widespread at all latitudes or rapid polar wandering occurred during the late Precambrian. They observe, however, that there is little evidence to favor the latter of these hypotheses. Paleomagnetic determinations on Cambrian and Precambrian rocks in Northern Europe, Greenland, and North America place the location of the north pole in an area near the equator in the present Pacific;

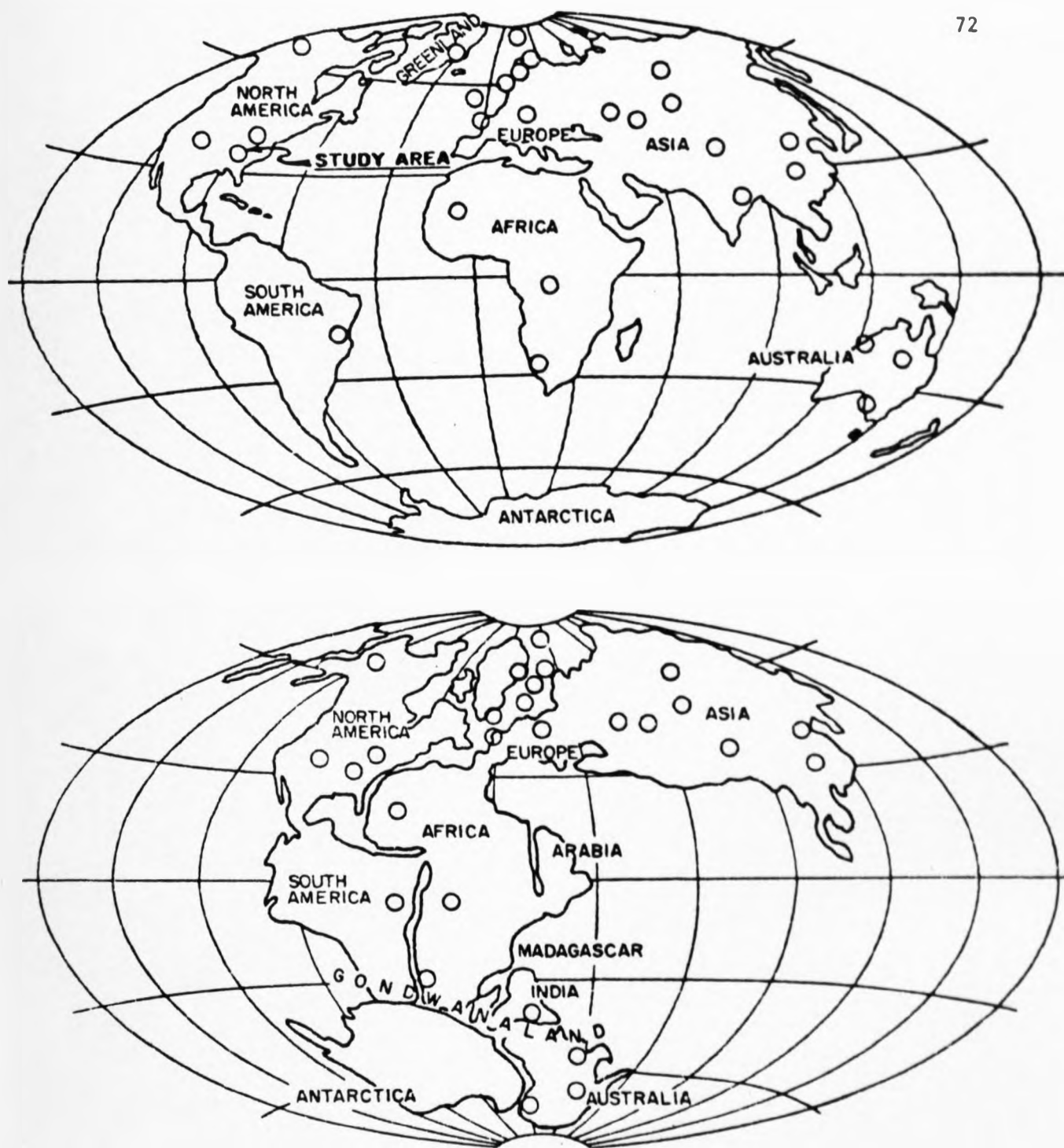


Figure 20. Distribution of Infra-Cambrian Tillites
 upper figure: present distribution of
 Infra-Cambrian tillites
 lower figure: possible distribution in
 Infra-Cambrian time

Modified From: Harland and Rudwick, 1964

determinations on sedimentary rocks closely associated with tillites in southern Norway and eastern Greenland indicate near equatorial latitudes (Harland and Rudwick, 1964; Girdler, 1964).

Criteria for the Recognition of Ancient Glaciations

The principle evidence for the recognition of ancient glacial deposits (Hamilton and Krinsley, 1967; Wandes and Cannon, 1966; Frankes and Crowell, 1967; Schenk, 1965; Crowell, 1964; Schwarzbach, 1964; Harland et al, 1966; Harland, 1964; Harland and Rudwick, 1964; and Wilson and Harland, 1964) includes the presence of massive, non-sorted debris (tillite) containing abundant clay-free rock flour consisting of silt and fine-grained sand of multimodal grain size and abundant fresh grains of easily weathered minerals and rock debris. These units override or are closely associated with a grooved and striated pavement and frequently contain faceted and striated pebbles, cobbles, and boulders. The most compelling and critical evidence of cold-climate deposition is the presence of laminated and graded, fine-grained varves consisting of alternating light and dark layers and containing numerous ice-rafted outsized dropstones which penetrate and deform underlying laminae (Harland et al, 1966; Crowell, 1964; Harland and Rudick, 1964; and Wilson and Harland, 1964). Further evidence includes the presence of associated lenses or sheets of polymictic conglomerates and sands of probably glacio-fluvial origin.

Several processes and environments of deposition must be considered in evaluating the genesis of sedimentary sequences resembling glacial deposits, and the mode of origin of tillite-like conglomeratic mudstone units (Crowell, 1967). Sedimentary units containing large clasts dispersed in a matrix of finer material and associated with graded rhythmities containing isolated clast are easy to recognize, but criteria to distinguish between the diverse possible origins are elusive (Crowell, 1964). Several writers (Crowell, 1964; Crowell, 1957; Dott, 1961; Crowell, 1967; Lindsey, 1969; Winterer 1964; and Schwarzbach, 1964) state that masses of rocks resembling tillites contain internal features and relationships which allows interpretation of the various origins. Crowell (1964) summarizes the possible origins as: (1) deposition by glaciers as till; (2) downslope movement or slumping in both marine and non-marine environments; (3) mudflows, both subaqueous and subaerial; (4) mixing and down-current movement caused by the impact of vigorous turbidity current; (5) milling and mixing within and beneath giant slide blocks which grade continuously in size up to immense thrust plates; (6) volcanic mudflows and lahars; (7) talus debris along escarpments, both subaqueous and subaerial; and (8) selective weathering or alteration of conglomerates in place.

Recently the most important of these possible alternatives is that of submarine slumping and turbidity currents; several units interpreted as glacial sequences have been restudied and ascribed to mass-movement deposition. Because of the existence of alternative modes of origin the proof of a glacial origin of a sedimentary sequence will depend on a fairly complete knowledge of both the rocks and their geological environment (Crowell, 1957).

Origin and Characteristic Features of Glacial Deposits

Although it is not possible to establish a mode of origin for the conglomeratic mudstone based solely on characteristics of the rock itself, its close association with other units interpreted as being of peri-glacial origin, such as varved argillites, suggests a glacial environment. The origin and characteristic features of tillites are summarized by Harland, Herod, and Krinsley (1966). They observe that tills may be formed either by immediate release from the transporting ice or by gradual release from slowly melting floating ice. Terrestrial deposition, where the base of the glacier is above sea level, is described under one of three processes: (1) ablation and melting, (2) lodgment, and (3) dumping. They further state that according to Carey and Ahmad (1961) wet-base and dry-base glaciers show differences in terrestrial glacial deposition, and where seagoing glaciers become floating ice sheets, lead to two distinct glacial marine depositional

environments. In wet-base glaciers, melting and lodgment produce till beneath the ice, and, beyond this, submarine outwash deposits may form on the sea or lake floor and icebergs break off at the surface. The wet-base glaciers are characterized in the ground shelf area by extensive sub-glacial till, with occasional stratified layers due to temporary floating of the ice and extension of the floating shelf zone. In the normal shelf zone, deposition beneath the ice would be dominantly by aqueous flow from meltwater and only incidently by rafting (Harland, Herod, and Krinsley, 1966). In dry-base glaciers ice flows without deposition until it is floated, and then it thins rapidly and floats as an ice shelf for some distance before breaking into bergs; these dry-base glaciers result in deposition by rafting, confined to the marine or lacustrine areas beyond the ground shelf zone.

Large clasts generally require efficient transporting agents. Moving water is effective only if velocities are high but these high velocities are incompatible with simultaneous deposition of large outsized clasts and fine-grained, laminated sediments. Ice is recognized as being able to transport large boulders over great distances along with materials of all grain sizes, but other agents and processes have produced similar results and require consideration (Crowell, 1964). Criteria for distinguishing

tillites from sediments resulting from mudflows, landslides, or volcanic explosions, etc. and in recognizing ice as an active agent in their formation have been summarized by Harland, Herod, and Krinsley (1966): variety in clast composition, rock flour matrix consisting of easily weathered minerals, complete absence of sorting and large variation in grain size, size of the largest boulders, graded bedding, frequency and distribution of stones, relation of stones to stratification (i.e. striated and gouged surfaces and percussion marks), thickness of stratification units, extent of stratification units, and striated and grooved pavements. It should be noted that many of the above characteristics can be produced by other processes, thus making difficult attempts to established the origin of such units solely on the basis of their own characteristics. All these evidences require very careful interpretation, since they can be explained in more than one way, but if all or most are present together may justify a glacial origin (Harland, Herod, and Krinsley, 1966).

Meltwater varved deposits of fine texture are formed in glacial lakes and in quiet marine environments where glaciers reach the sea (Wandes and Cannon, 1966). Deposits similar to those of varved sequences are found in geosynclinal successions and are believed to represent distal turbidites or bottomset beds of large

deltas. Some volcanic ash beds deposited in quiet lake and marine environments may resemble varves in structure (Wandes and Cannon, 1966). The erratic rock fragments or isolated pebbles and cobbles embedded in varve-like fine-grained deposits are frequently interpreted as the result of melting shelf ice or icebergs releasing material over sea or lake bottoms; however, it is known that floating kelp holdfasts may raft similar rock chunks into quiet-water environments (Crowell, 1957; Wandes and Cannon, 1966). In a few instances, beds containing isolated clasts scattered along bedding planes by a sudden swift current may be difficult to distinguish from glacial varve sequences (Crowell, 1957).

DeGeer (1912), proposed that varved clays are deposited as underflows or turbidity currents by sediment-laden meltwaters in glacial lakes. However, Antevs (1925, 1951) believed that meltwaters, because of their lower temperature and resulting lower density, remain at the top of the water column and spread transporting sediments within the upper water layers from which they settle out. It has also been suggested that there is a general mixing of meltwater and lake water, the sediment thus becoming diffused through the entire body of standing water and then settling to the bottom in the course of a year (Kuenen, 1951). Kuenen (1951) proposed a special type of annually produced turbidity current as the cause of glacial varves by pointing out that the sediment-laden meltwaters flowing away from the

ice-contact must be more dense than the clear lake water and consequently must flow along the bottom of glacial lakes without rising to the surface (Kuenen, 1951; Lajtai, 1967; and Banerjee, 1966). The hypothesis of Kuenen (1951) and DeGeer (1912) is preferred for three reasons: (1) Kuenen (1951) and Lajtai (1967) state that the effective density, which controls the path of sediment-laden currents when they enter lake or marine environments, depends more on the difference in sediment concentration than on temperature differences as proposed by Anteys (1925, 1951); (2) that recent field observations demonstrate that sediment-laden waters do plunge beneath the surface and continue along as bottom currents (Lajtai, 1967); (3) most characteristics shown by varves are similar to those of deposits produced by turbidity currents (Banerjee, 1966; Lajtai, 1967).

Varves may be recognized by a number of characteristics which are similar to those of turbidites: (1) individual units covering large areas without significant change in thickness; (2) occurrence of mud pebble or rip-up clasts; (3) erosional markings at the bottom of some beds; (4) sharply defined lower boundaries; (5) general decrease in grain-size from bottom to top; and (6) occurrence of horizontal laminations (Lajtai, 1967). The extreme cyclicity and regularity in thickness of varves as opposed to turbidites is an important criteria. The most compelling evidence of a glacial origin is that many varved sequences contain numerous ice-rafted outsized clasts which penetrate and deform underlying laminae.

Banerjee (1966) presents evidence for varves being formed by turbidites generated from the slumping of oversteepened and overloaded fronts of an outwash delta built within a glacial lake. Kuenen (1951) indicates that meltwater turbidity currents in glacial lakes differ from normal turbidity currents in that the latter are set up by a sudden release of a body of turbid water, whereas, meltwater supply continued for long periods of time. Kuenen, and Lajtai use this relatively constant velocity and sedimentary load and their variations to explain many varve characteristics.

Due to sedimentation from a continuous current, varve formation is effected by three independent but overlapping sedimentary processes: (1) deposition from a graded suspension; (2) addition from rolled coarse material; (3) deposition from an independent uniform clay suspension (Lajtai, 1967). Most varves do not exhibit the typical turbidite graded bedding in which the maximum grain size gradually decreases from bottom to top but show rather a generally poorly-sorted coarse layer and an upper fine layer with a sharp contact between them. Kuenen (1951) explains this difference as being due to the near constant velocities and sediment loads. As long as these remain constant the material being deposited will not vary at any one point but when the warm season draws to a close the maximum grain size of the deposit becomes smaller. The sharp separation between summer and winter laminae in these varves is explained by the fact that in some

localities winter deposition does not start until a period of time after the turbidity current has become stagnant. In the zone near the ice coarse material is transported a short distance and is deposited first, resulting in proximal and near proximal varves which have thick and comparatively coarse summer lamina and relatively thin winter lamina. In general the winter clay layer increases in thickness and the summer layer decreases in thickness with distance from the ice. In these distal zones fine clay particles remain in circulation, therefore storing much clay during the summer and the relative contribution from surface spreading increases forming relatively moderate to thick winter laminae (Kuenen, 1951; Antevs, 1951). This gradual decrease in the coarseness and thickness of the summer lamina with distance from the meltwater source is due to a gradual horizontal decrease in the velocity of the transporting current (Antevs, 1951). Normally varves are made up of a single coarse, light-colored lamination, deposited in summer and of a fine, dark-colored lamination deposited in winter, but pulsations in both water volume and content of suspended load occur, resulting in the formation of minor sub-laminations (Antevs, 1951; Kuenen, 1951). These pulsations are related to temperature variations that in turn control the melting of the ice, the discharge of meltwaters, and consequently the concentration and the maximum size of the sediment load (Lajtai, 1967). The direct result of this is that during cool periods the

weather would limit or prevent the melting of ice and therefore lead to a diminishing sediment discharge and deposition of fine-grained sediments forming thick well developed clay lamina in winter and minor clay sub-laminations in cool summer periods (Lajtai, 1967; Antevs, 1951; Kuenen, 1951). During warm periods of weather, increased melting of ice would result in higher discharge and a coarser sediment load forming coarse lamina in summer and silty sub-laminations within the winter lamina during warm periods.

Penetration and distortion of underlying laminae by large stones is generally regarded as the most compelling evidence for rafting (Harland, Herod, and Krinsley, 1966; Crowell, 1964; Harland and Rudwick, 1964). The following is a summary of evidence presented by Harland, Herod, and Krinsley (1966) for ice rafting. They state that the abundance of large stones, especially in the Precambrian and early Paleozoic, rules out biological rafting. Distortion of laminae may be due to compaction of clays but if underlying layers are clearly disrupted and penetrated, rafting is indicated. If the diameter of the larger clasts exceeds the thickness of the beds or laminae, these stones (outsized clasts) could not have been carried laterally into place contemporaneously with the finer sediment. This evidence must be used in conjunction with random distribution of the outsized clasts with respect to the strata, because small stones arranged along distinct bedding surfaces could be the result of current action on a pebbly deposit of any origin (Harland, Herod, and Krinsley, 1966).

Paleoenvironments of the Mount Rogers Formation

Evidence for a glacial and periglacial environment of deposition for much of the Mount Rogers Formation is compelling. The sedimentary units of the upper member of the Mount Rogers Formation are interpreted as a sequence of deposits including tillite (conglomeratic mudstone), glacio-lacustrine or glacio-marine varves and interbedded turbidites (rhythmically layered argillites), and periglacial alluvial sandstone and conglomerate (arkosic sandstone and conglomerate and polymictic conglomerate) (Table III). The major evidence for a glacial and periglacial origin is summarized below.

(1) Thick sequences consisting of thin, repeated, graded fine-grained laminae containing isolated "outsized clasts" which penetrate and deform underlying laminae, such as those in the argillite sequences, can be explained only as glacial varves and ice-rafted dropstones. These varves show typical varve characteristics: individual units cover large areas without significant change in thickness; they contain basal shale rip-up clasts; erosional markings occur at the base of some beds; lower boundaries are sharply defined; general decrease in grain-size from top to bottom; and the occurrence of minor sub-laminations.

LITHOLOGY	INTERPRETATION
Conglomeratic Mudstone	Glacial-Ground Moraine Stratified Tillite
Rhythmites	Glacial-Varves
Polymict Conglomerate	Glacio-Fluvial-Alluvial Fan
Arkosic Sandstone	Periglacial-Alluvial Lacustrine Marine

TABLE III

Interpretation of Mount Rogers Lithologic Units

(2) The association of glacial varves with massive, unsorted conglomeratic mudstone containing clasts set in a matrix of clay-poor rock flour, silt, and fine sand which includes fresh grains of easily weathered minerals and rock debris suggests that the latter represents tillite. These units show a wide range of clast compositions, complete absence of sorting and large variations in grain size, large areal extent, thinness relative to their lateral extent, and clasts which appear faceted in cross section.

(3) The lithologic association of tillite, varved argillite, and glacio-fluvial debris (alluvial sandstones and conglomerates and polymictic conglomerates) is similar to the sedimentary associations of Pleistocene, upper Paleozoic, and upper Precambrian sequences of known glacial and periglacial origin, such as those of the Gowganda Formation of southeastern Canada.

(4) There is much evidence for a wide spread late Precambrian glaciation, and the Mount Rogers Formation has been well established as late Precambrian.

(5) From evidence available it is possible to eliminate other modes of origin which are known to form sedimentary sequences resembling glacial deposits, thus reinforcing the inferred glacial origin. Volcanic mudflows and tectonic milling can be eliminated because particles and fragments of primary volcanic ejecta are absent and evidence of large-scale faulting in association with the conglomeratic mudstone is absent. In an

environment where sedimentation was dominated by pyroclastic volcanism, it would be difficult, if not impossible, to explain the predominance of outsized plutonic and metamorphic debris. The lack of diagnostic features of tillites and mudflows makes them difficult to distinguish. However the associated interstratified varved argillites of almost certain glacial origin provides evidence as to the origin of the massive diamictites. Conclusions concerning environment, derived from stratified interbeds, serve as a paleogeographic framework into which the diamictite-forming processes must logically fit (Frakes and Crowell, 1967). Subaerial mudflows resemble tillites but can be differentiated on the basis of their association of interbedded deposits; these mudflows are interbedded with alluvial fan and related deposits and mudflows rarely reach playa deposits. It would also be difficult to explain the widespread random distribution of outsized clasts in this environment. According to Heezen and Hollister (1964), tillite is easily distinguished from turbidity current deposits. Turbidites are distinctly stratified, graded and moderately- to well-sorted with flow marks, scour marks, and flow casts on their lower bedding surfaces. They also show convolute laminations, small-scale cross-beds and slump structures and frequently show randomly distributed outsized clasts. The

Mount Rogers tillites are generally characterized by the lack of stratification, grading, sorting, and current generated structures. Thick repeated sequences of graded beds as found in flysh deposits are not found in the Mount Rogers upper sedimentary member.

Subaqueous mudflows and turbidites may be eliminated because of the extreme regularity in thickness and repetitiveness of the varves; turbidites are generally of variable thickness and separated by variable thicknesses of non-graded massive mudstone; and finally, turbidite outsized clasts are generally of intraformational rip-up origin and localized in the coarse-grained portion of the bed; therefore, the content of randomly distributed outsized exotic clasts cannot be explained by turbidity currents. Weathering and alteration of conglomerates in place can be eliminated because of the content within the tillites of easily weathered minerals and rock debris.

Paleogeography of the Upper Sedimentary Member

An environmental model and generalized paleogeography can be constructed from broad stratigraphic relations, paleocurrent directions, nature of the source area, dropstone distribution, and facies relationships.

This model (figure 21) shows a glacial marine or lacustrine basin associated with a basement and volcanic highland which was undergoing rapid erosion and glaciation. This landmass, which was probably of considerable size, lay to the south and southwest. Abundant plutonic pebbles, rhyolite fragments, and feldspar grains indicate that this source area included subaerial exposures of the Cranberry Gneiss and volcanics of the middle member of the Mount Rogers Formation. Rock fragments within the tillites include granites, granitic-gneiss, rhyolite, and basalt. The abundance of easily weathered minerals and rock fragments indicates that chemical weathering of this sialic basement was slight, erosion rapid, and transportation short.

There are several lines of evidence that the conglomeratic mudstones, which are interpreted as tillite, were deposited as ground moraine beneath grounded glacial ice which advanced from the southern and southwestern quadrants and periodically intruded into standing marine or lacustrine environment (figures 21-23). Interbedded with these units and directly above units which are interpreted as being of glacio-fluvial origin in the northwestern sections are thick units of stratified tillite (laminated pebbly mudstone). These stratified units are interpreted as the deposit

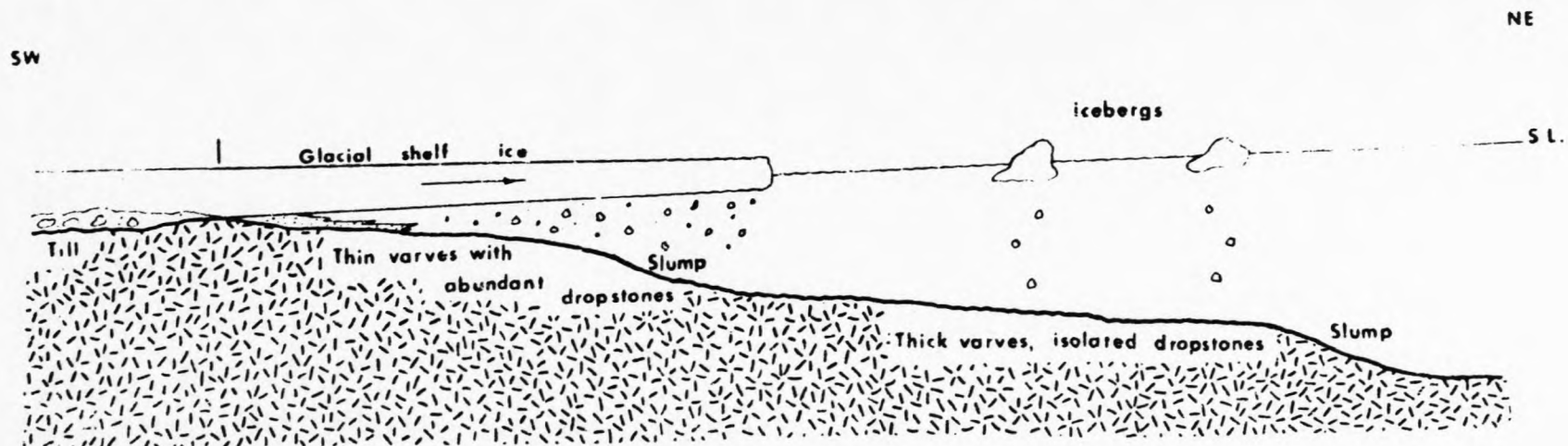


Figure 21: Environmental model for the upper sedimentary member of the Mount Rogers Formation

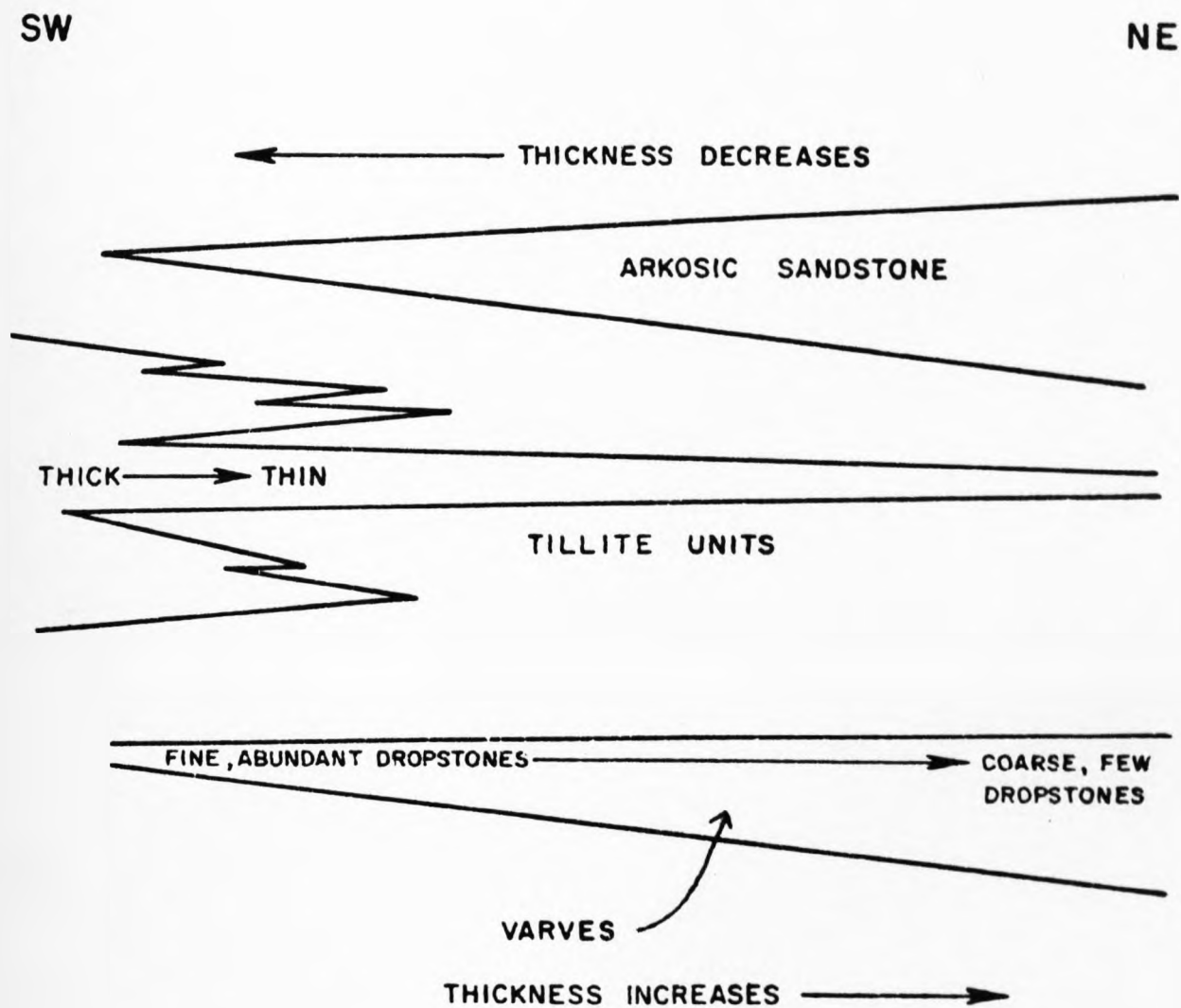


Figure 22: Facies evidence for direction of ice movement

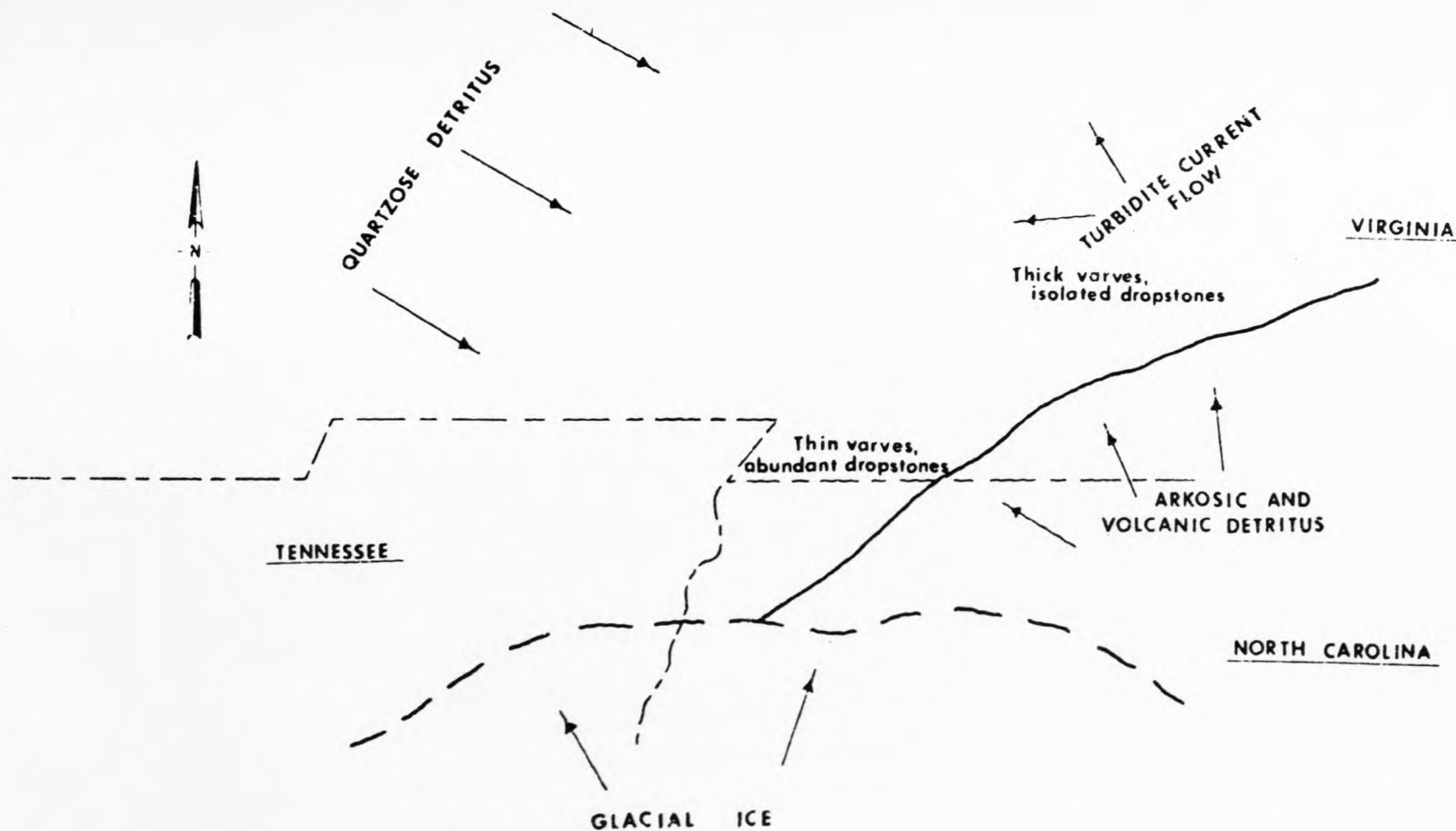


Figure 23: Generalized paleogeography and directional information of the study area

of debris laden ice which extended into the site of deposition. As this ice melted, large amounts of detrital fragments were dropped and settled to the bottom without any additional sorting. The presence of interbedded stratified tillites, as opposed to strictly massive tillitic units, indicates deposition in the vicinity of the transition zone where the grounded glacial ice extends into the marine or lacustrine environment as shelf ice. In the southwestern sections of the study area there are several thick units of massive tillite which thin and are in facies with sandstones and argillites to the northeast. One such unit extends across the study area, thinning to the northeast, providing further evidence for a general south to north or southwest to northeast movement of late Precambrian ice and indicating that the entire area was covered by ice at one time (figure 22). Additional variations in the position of the ice front are indicated by the occurrence of several thick, massive tillite units in southwestern sections and by the local interbedding of the micro- and mega-rhythmites.

The varved argillites were deposited in a basin which deepened to the northeast as is indicated by the facies relationship of the microrhythmites (fine varves) and the megarhythmites (coarse varves) (figures 21-23). These units were deposited within a periglacial environment of low circulation and considerable ice rafting.

Glaciers occasionally moved down into the standing marine or lacustrine environment and were the major source of detritus to the varved deposits. These varve sequences represent uninterrupted, very quiet water sedimentation under conditions of alternating surface freeze (fine, hemipelagic varve tops) and summer thaw (coarse varve bottoms). Studies of varve thickness and dropstone abundance lend further support to the direction of ice sheet movement. The microrhythmites or fine varves, which contain abundant dropstones, are interpreted as representing a proximal or marginal subglacial equivalent and are the dominant varved facies in southwestern sections (figures 21 and 23). These varves represent deposition within a zone near the ice front; most varve detritus was discharged from beneath the ice by meltwaters. Most of the coarser sand and conglomeratic material was dropped from the glacial ice which at times extended into the shallow water environment as shelf ice. The megarhythmites containing only isolated dropstones are considered as distal or offshore and represent the dominant facies in northeastern sections (figures 21 and 23). These units show thick winter clay lamina, thin summer lamina, and contain only widespread, randomly distributed dropstones. Most of these dropstones were probably rafted in within large floating masses of ice (icebergs).

The minor interbedding of fine and coarse varves reflects variations in meltwater discharge, abundance of detritus, fluctuations in the position of the ice front and shelf ice, or some combination of these. The presence of slump units and mud-chip breccias indicates deposition on or near the base of a subaqueous slope. These varve differences, if interpreted in the context of a marine environment, could represent deposition within a quiet arm of the sea (a bay sequence) in which the fine varves represent proximal to ice, shallow water sedimentation and the thick varves quiet, more rapid, distal, somewhat deeper water sedimentation. Similar facies might equally well characterize a large lake.

The general lithologic association of coarse-grained, poorly-sorted arkosic sandstone and conglomerate and polymictic conglomerate indicates deposition within or close to a high energy alluvial environment. However only the polymictic conglomerate contains sedimentary structures and textures unequivocally indicating an alluvial origin. It is interpreted as a deposit of a glacio-fluvial, sub-glacial, or outwash stream which extended into the quiet, standing water environment.

The bulk of the arkosic sandstones and conglomerates is relatively massive and occurs interbedded with fine-grained varved argillite. This close association of contrasting quiet water and high energy deposits suggests that the latter were dumped into the quiet environment, as from an alluvial system draining into a lake or quiet arm of the sea. These sand bodies are interpreted

as either alluvial-front sheet sands of glacial streams which advanced and filled the basin or as the distal portions of glacial outwash plains which extended into the marine or lacustrine environment. According to Wanless and Cannon (1966), when associated with other known glacial deposits, coarse- to fine-bedded conglomerate and sand deposits may be expected as glacial outwash material. Paleocurrent data indicates that these units were washed into the basin from the south and southeast and show distinct thinning to the southwest (figures 21 and 23). The current data also indicates that the small-scale turbidites (graded sandstone showing Bouma intervals) associated with the megarhythmites in eastern sections were flushed into the basin from the same general direction (figure 23). These units are attributed to small-scale turbidity currents generated by slumping either from an oversteepened delta front, from thick accumulations of material carried out from under the moving ice, or from unconsolidated sediments accumulating rapidly on steep basal slopes.

Marking the top of the sequence are thick units of quartz pebble conglomerate; the source area of these units was definitely different from that of the bulk of the Mount Rogers Formation. Imbrication within these units indicates a general north to south direction of transport and is indicative of the gradual shift in importance of source areas between Mount Rogers and

Chilhowee time; the influence of the North American craton becoming the controlling factor during Chilhowee deposition.

In summary, the general paleoenvironmental association represented by the upper sedimentary member of the Mount Rogers Formation is that of a basement and volcanic highland which was undergoing rapid erosion and glaciation. Glacial outwash systems extended from these highlands and from the fluctuating glacier fronts, transporting large amounts of detritus into quiet, sheltered marine or lacustrine bodies of water which underwent annual freeze-thaw cycles and varve deposition. Glaciers occasionally moved down into this standing marine or lacustrine environment and frequently extended as shelf ice transporting glacially derived debris to the varved deposits (figure 21).

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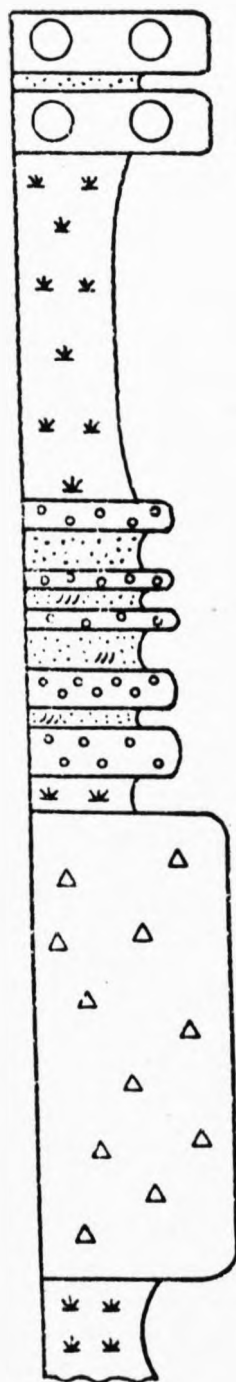
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APPENDIX

Note: For detailed location of the following measured sections see corresponding number on geological map (Plate I) in map pocket.



145' Basalt

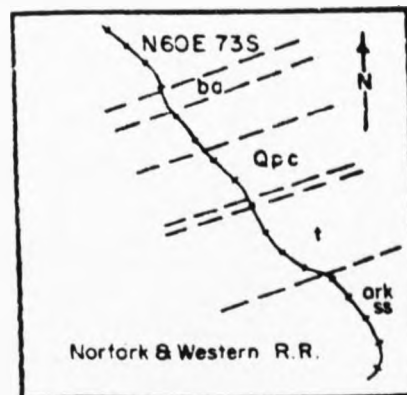
355' Covered (arkosic ss&cgl)

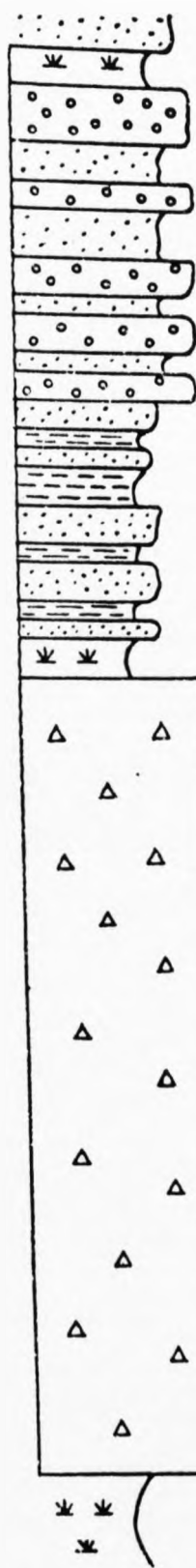
295'

Quartz pebble cgl w/interbeds of f to c grained ark ss & cgl, local x-bedding. Qtz pebbles are well-sorted in an ark ss matrix, pebbles are well-rounded and avg 1" in dia., 3" max., clast comp. - approx. 80% qtz, 20% feldspar, chert, minor rock frag.

475'

Tillite - massive, well-indurated, matrix-supported, red, hematitic conglomeratic mudstone. Large ang to sub-ang clast lack any sorting, max clast size in inches 10, 12, 9, 4, 10, 12, 13, 6, 5, 8; avg clast size greater than 1" = 2"; %clast greater than 1" = 5%; comp. clast greater than 1" - 97% granitic gneiss; 3% qtz, rhyolite, mudstone, basalt, other volcanics and metamorphics. Matrix consists of dark brownish-red hematitic mudstone.



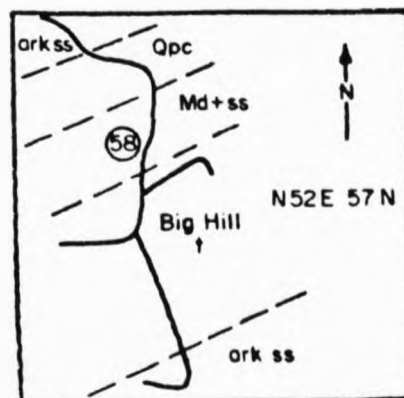


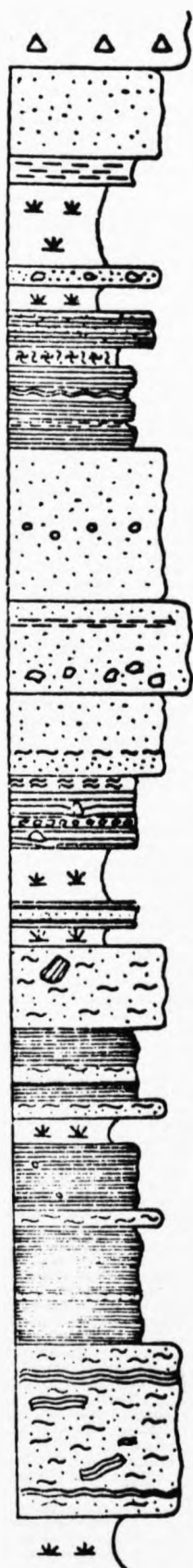
335' Qtz peb cgl inter w/
f to c gr., p. sorted
ark ss & cgl. Qtz peb
w. sorted, imbricated,
avg. 1.5" dia, 4" max,
isolated feldspar
clasts, 1" max, minor
chert & other rk frag;
matrix - p. sorted ark ss

251' Shale - maroon to dk gray, massive, no varves
noted; thin interbeds of arkosic sandstone
are fine to coarse-grained, poorly-sorted;
no cross-beds or laminations were noted in
this section.

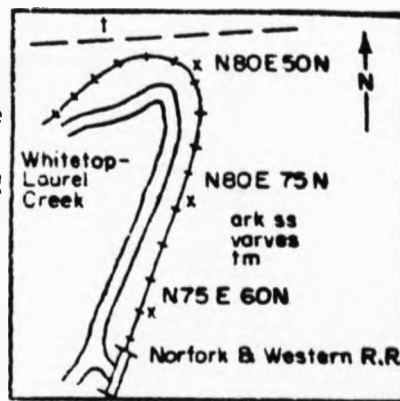
40' Covered

840' Tillite - massive, matrix-supported, red,
hematitic conglomeratic mudstone. Angular
to sub-angular clasts lack any noticeable
sorting. The maximum clast size in inches
are as follows: 9, 6, 3, 4, 5, 7, 4, 6, 6, 6; average
clast size greater than 1" in diameter is
1.5"; the % of clast greater than 1" in
diameter is 2-3% maximum; the composition
of clast greater than 1" in diameter is as
follows: 95% granitic - gneiss, 2% rhyolite,
3% other including quartz, basalt, and
mudstone. The matrix consists of dark brownish-
red hematitic mudstone.

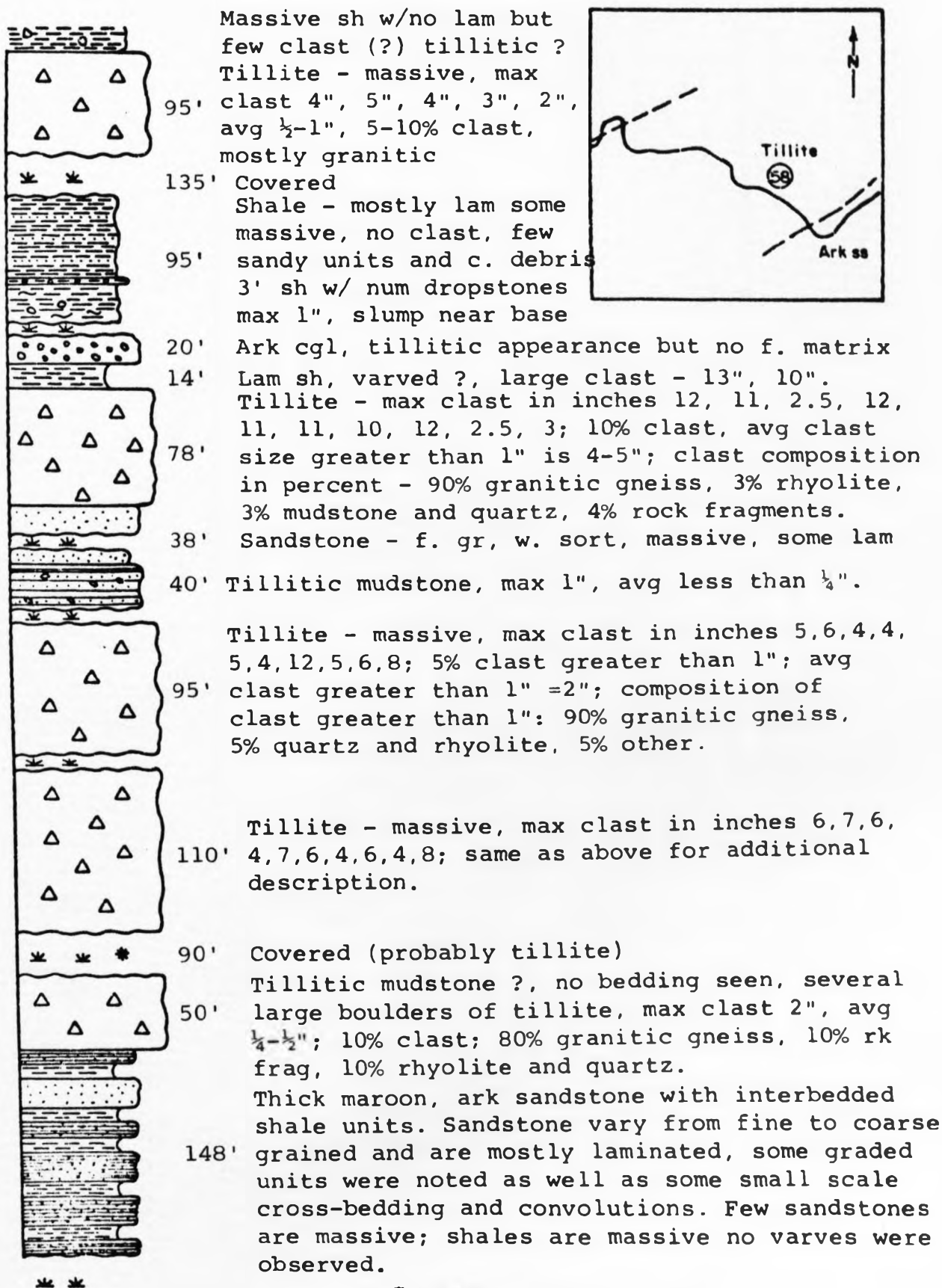




- Tillite - massive, max clast 2', avg 2", 30% clast, mostly gr. gneiss Sandstone, f. gr, massive
- 50' some minor laminations, minor thin shaly interbed
- 14' Shale- silty at top
- 50' Covered
- 5' F. gr ss w/granitic clast
- 15' Covered
- 20' F. gr ss, lam, w.sort
- 10' Sheared zone - mineralized
- 45' Varves, v.fine, no dropstones, some contorted; varve count: 21 in 1"; 44 in 3"; 92 in 3".
- Ark ss & cgl- ss white to gray, w. sorted, f to c gr, finer towards top. Ark cgl contains v. ang feldspar grains. No structures were noted in this unit.
- 85'
- Sandstone - f. gr, maroon, massive, no structures were noted, minor siltstone zones. Basal 20' tillitic md ?, slt w/num. ang granitic clast, max 4"
- 48'
- Sandstone - massive, maroon, f to m gr, w. sort, numerous shale clast, minor fine lam and x-beds
- 45'
- Varves- v. fine, num. dropstones, granitic (95%), max 3', varve count: 40/3", 12/3", 8/2"; 5' slump unit at top; clast- 2", 3", 6", 2", 1", 3".
- 40'
- 27'
- 15' Varves, med, few clast, count: 6/3", 9/6".
- Slump unit- ss w/ num sh clast, some fine varve
- 45' blocks, equal ss sh mix, no dropstone or clast.
- 38' Varves, fine, few clast, max 1/4", mostly granitic
- 5' sandstone slump unit
- 10' Sandstone, massive, m. gr, few sh chips
- 35' Varves, fine at top, med middle, fine at base
- few to no clast, count: 17/2" top, 8/5" mid, 9/2" base.
- 8' Slumped varves and ss
- 67' Varves, medium, many clast which in some cases form distinct layers, max clast 1.5", 1", 2", count: 23/6", 8/2", 8/2", 5/2", 18/6".
- Slump unit - mostly varved mudstone, fine to med varves, very few to no clast, much ss with
- 95' shale rip-up clast; many contorted varves and blocks of varved material in slumped unit.

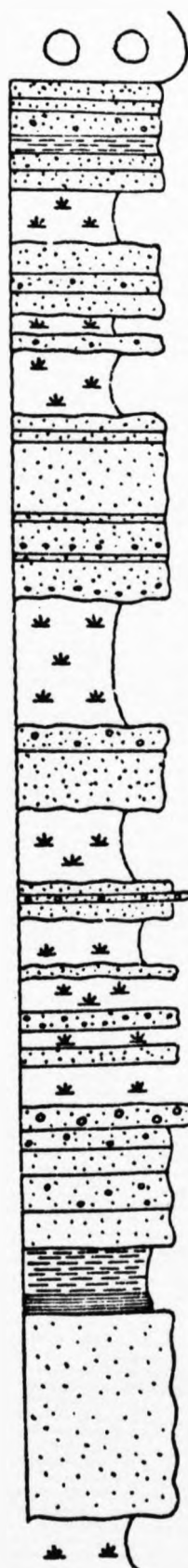


CREEK JUNCTION SECTION



* Note: Covered Sections Decreased

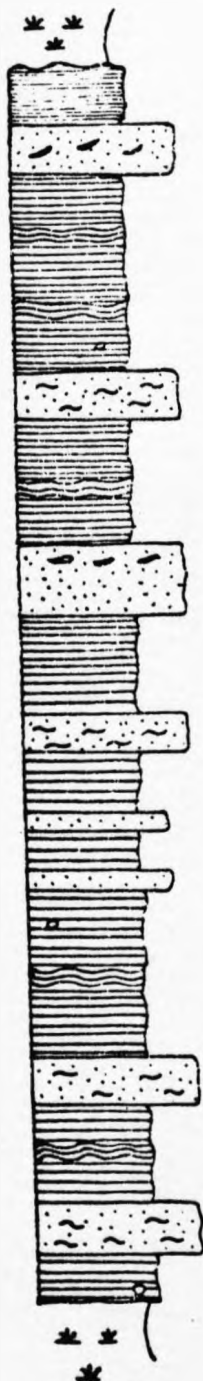
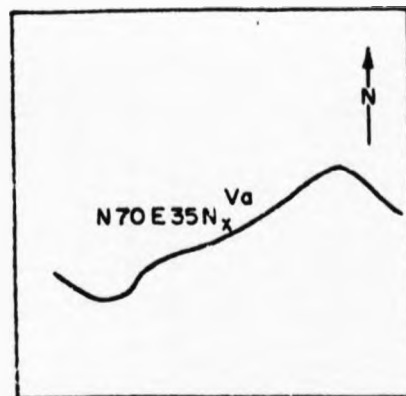
BEAR TREE GAP SECTION



- Basalt
- 122' Interbedded ark ss & cgl and mostly qtzitic cgl & ss; 1' maroon shale, lam.; cgl are massive, max clast $\frac{1}{2}$ " minor x-beds, some units graded; qtzitic units are w. sort, ark units p.sort.
- 66' Covered
- 86' Interbedded qtzitic cgl & ss, no structures noted, m to w.sort, mostly conglomerate.
- 21' Conglomerate, 75% qtz, 25% feld clast, max $\frac{1}{4}$ ".
- 73' Covered
- 90% ark cgl w/10% interbedded ss units, mostly coarse-grained w/local small scale x-beds. Cgl contain 50% qtz and 50% feldspar, the qtz is w. rounded the feldspars very ang., lower 40-50 feet is more qtzitic than upper units.
- 204'
- 143' Covered (abundant fine-grained ark sandstone float)
- 91' Ark ss and cgl- ss are c gr and p.sort, local x-beds, many units graded; max clast size in cgl is $\frac{1}{4}$ - $\frac{1}{2}$ ".
- 85' Covered
- 40' Qtz pebble cgl, 10' unit, max 1", avg $\frac{1}{2}$ ".
- 50' Covered
- 187' Mostly covered - interbedded ark ss and minor qpc, basal 20' Qpc, max 3", avg 1", qtz pebbles well-sorted in ark ss matrix, no imbrication.
- 132' Interbedded ark ss and cgl, max clast size $\frac{1}{2}$ "; Sandstones are massive, no x-beds noted; in upper cgl pick up more qtz pebbles.
- 73' Mudstone, mostly massive, no laminations or clast; bottom 15' varved, 12/1".
- 232' Sandstone - ark, fine to coarse-grained, ss are finer towards top, mostly lam especially upper ss units, no structures were noted.

WEAVER'S SECTION "B"

NOTE: Section measures 124', for details see following two sections. The section below is diagrammatic but relative position of units is correct.



Sandstone - massive no structures, many shale rip-up clast, coarse-grained sharp basal and upper contacts

Varves - large, max size 4", 3.5", 6.5", 9.5"; some contorted units and isolated dropstones.

Slump unit, general location - many throughout, sand and shale mix, numerous shale rip-up clast.

Sandstone - massive, see detailed section 2, sharp upper and lower contacts, numerous shale rip-up clasts and varved clast.

Slump unit as above

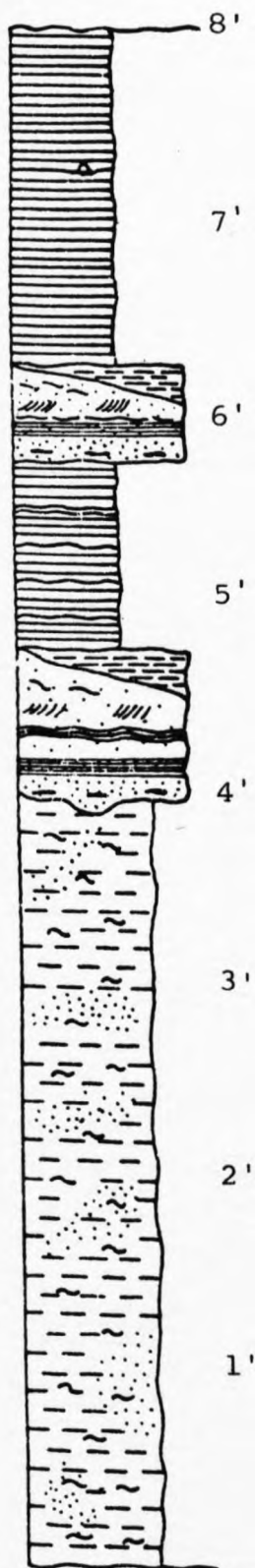
Turbidites - Bouma sequences (see detail 1)

Varves - thick with scattered granitic dropstones, many of these varved units are contorted, interbedded within these varves are slump units, mostly sandy with shale rip-up clast; 11/5", 15/6", 10/6", 10/6", 11/6"; average 1/2-1".

Slump unit as above

Varves as above

DISCOVERY VARVE SECTION



Varves - $6\frac{1}{2}'$, max 1", avg $\frac{1}{2}"$, one dropstone found - 1.5" in diameter

7'

6'

Turbidite - graded sandstone showing Bouma structures; varies from 4 to 9" in thickness, rip-up clast in basal portion, sharp lower contact, upper contact gradational into pink claystone.

5'

Varves - $6\frac{1}{3}"$, $7\frac{1}{3}"$, $9\frac{1}{3}"$, $\frac{1}{2}"$ avg; mostly contorted, no dropstones found.

Turbidite - as above

4'

3'

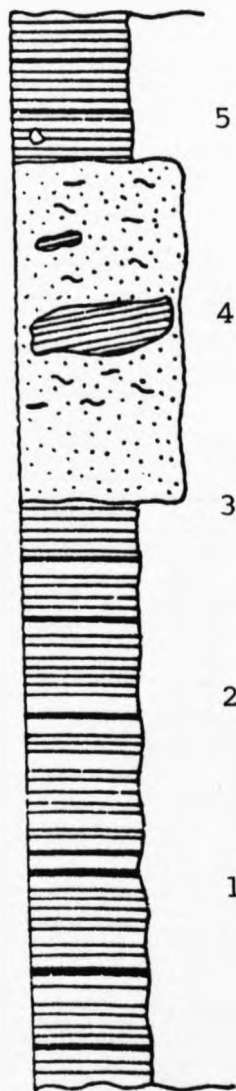
2'

Slump unit - shale unit with sandy zones, numerous shale rip-up clast.

1'

DETAILED VARVED SECTION (TURBIDITES)

8-1



Varves - 44/1', max $\frac{1}{2}$ ", dropstone 1.2"

5'

Slump unit - sandstone with abundant red shale and varved clast, these clast long dimension is parallel to bedding; basal portion (.5') is massive graded sand containing no shale clast or sedimentary structures, basal contact is sharp.

4'

3'

Varves - 20/6", 8/6", max $\frac{1}{2}$ ", no dropstones were observed, one $\frac{1}{4}$ " granule layer.

2'

1'

DETAILED VARVED SECTION (SLUMP UNIT)

8-2



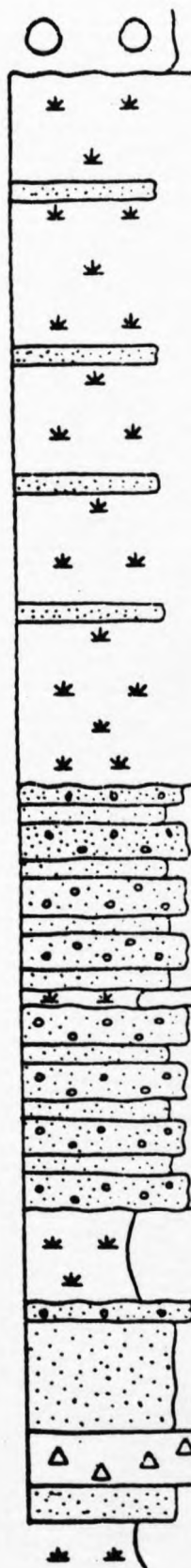
92' Interbedded slump units and massive arkosic sandstones with numerous shale and varved rip-up clasts. Sandstone are coarse-grained and well-sorted; few minor shale units.

60' Slump unit - same as below - mostly sandstone with shale and varved clasts; 4' varved zone at top of sequence underlain by massive maroon shale.

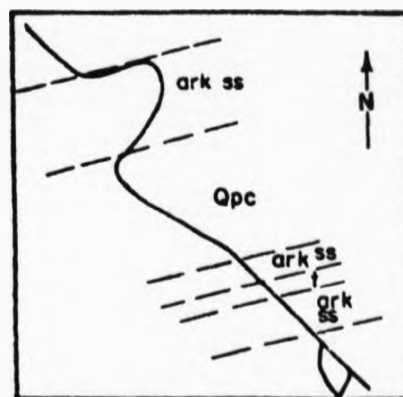
48' Covered

308' Both normal and highly contorted varves are found interbedded with numerous sandstone units - some thick and massive, many graded, several units exhibit good turbidite structures. Varves average between $\frac{1}{2}$ and 1 inch in thickness and contain very few dropstones, maximum 3", 1", 2.25" diameter, granitic gneiss. Interbedded with these units are massive arkosic sandstone units, fine- to coarse-grained, some with minor shale clasts. Con't Also found interbedded with these units are slump units which appear to be highly contorted or disrupted varved and sandstone sequences resulting in massive slump units. Towards the top of the section you lose both regular and contorted varves and pass into a zone of thick slump units and massive sandstone beds with shale rip-up clasts.

TROUTDALE SECTION
9 Con't



Basalt



1950' Covered - Mostly arkosic sandstone and conglomerate float - scattered poor outcrops, lower 150' good arkosic sandstone and conglomerate.

565' Quartz pebble conglomerate - quartz clasts well-sorted and rounded, max diameter 1-1.5", avg diameter $\frac{1}{2}$ ", no sedimentary structures, interbedded ark ss and cgl, lose Qpc in upper portion, basal 150-175' is mostly interbedded

50' ark ss and conglomerate, minor x-beds.

555' Quartz pebble conglomerate - upper 255' of section, coarser, mostly ark ss and cgl, Qpc avg $\frac{1}{2}$ " qtz clast and feldspar clast, Qpc units are well-bedded and continuous. Basal 300' is mostly fine ark ss, no structures or grading, no good Qpc in this portion.

255' Covered (Qpc)

40' Quartz peb cgl, well-rounded qtz peb in ark ss matrix, 1" max - $\frac{1}{2}$ " avg clast, inter ss, 265' fine to coarse, no structures.

Sandstone - covered, ark ss float, poor outcrop.

110' Tillite - max clast 7.5", 13", 12", 9", 6", 4", 2", 5"; avg clast 2"; 50-60% gr gn, 20% rhy, 20% other.

IRON MOUNTAIN GAP SECTION

VITA

Kenneth M. Blondeau, son of Alexander L. and Claire M. Blondeau, was born in New Orleans, Louisiana, on December 30, 1948, and was reared in Baton Rouge, Louisiana. He attended the Baton Rouge public schools and graduated from Robert E. Lee High School in June, 1966. The following September, he entered Louisiana State University in Baton Rouge, where he received his Bachelor of Science Degree in Geography in May, 1970. In July, 1970, he entered the Graduate School of Louisiana State University where he is working toward a Master of Science Degree in the Department of Geology.

He is married to the former Sally Lynn Spain of Galveston, Texas.

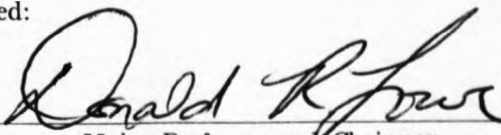
EXAMINATION AND THESIS REPORT

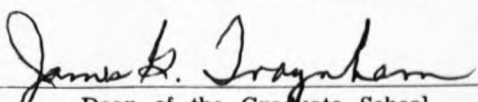
Candidate: Kenneth Morris Blondeau

Major Field: Geology

Title of Thesis: Sedimentation and Stratigraphy of the Mount Rogers Formation, Virginia.

Approved:


Major Professor and Chairman


Dean of the Graduate School

EXAMINING COMMITTEE:


Ray G. Stenell Jr.

Date of Examination:

December 5, 1972